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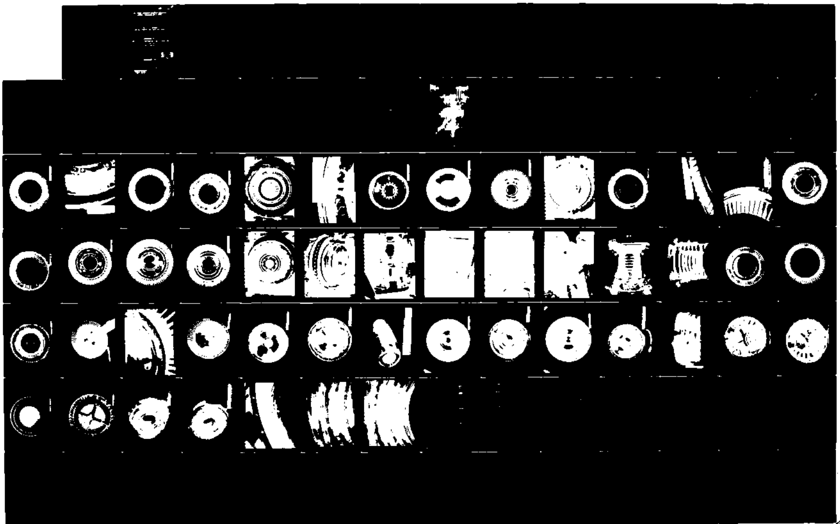

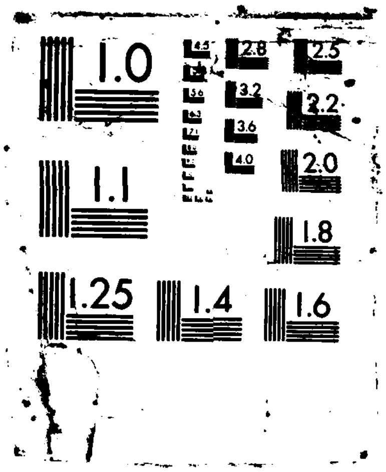
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AD-A192 765

T55-L-714 ENGINE
DEVELOPMENT AND QUALIFICATION

ENGINE M11
LOW CYCLE FATIGUE TEST REPORT

LYC 87-14
(0213-005-87)

DECEMBER 1987

[illegible]

U.S. ARMY AVIATION SYSTEM COMMAND
CONTR. #DAAJ09-87-C-A043

T55-L-714 ENGINE
DEVELOPMENT AND QUALIFICATION

ENGINE M11
LOW CYCLE FATIGUE TEST REPORT

LYC 87-14
(0213-005-87)

Reported by: J Kozub Jr.
J. Kozub
T55 Test Engineer

Approved by: R Hathaway
R. Hathaway
T55 Engine Test Manager

Concurred by: Jim F. Kolar
J. Kolar
T55 Engine Project Manager

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LIST OF ILLUSTRATIONS (Continued)

SUMMARY

T55-L-713 engine M-11C, which had previously completed 1000 cycles (250 hours) of low cycle fatigue (LCF) testing, was subjected to an additional 1000 cycles of LCF testing.

Testing ended when there was a failure in the power turbine section of the engine. The results of investigations completed up to the publication of this report indicate a third turbine blade failure. (See Report No. LYC 87-15 Engine M11 Failure Report).

Prior to the failure, the engine had satisfactorily completed 746 cycles (161.6 hours) of the scheduled second 1000 cycles. Thermodynamic deterioration was consistent with the number of cycles completed and there had been no significant mechanical or performance problems.

The average actual gas producer speed (NI), shaft horsepower (SHP), and power turbine inlet temperature ($T_{4.5}$) demonstrated was:

ARE LISTED.

	NI, % of 18,720 RPM	SHP	$T_{4.5}$	$T_{4.5}$ Required
Maximum	107.2	4737	1654°F	1650°
Max Continuous	103.3	4078	1507°F	1500°F

Acceleration times were within specification throughout the test.

	AMB	FI-MAX	SPEC	AMB	GI-MAX	SPEC
Pretest	98°F	4.8 Sec	4.4-5.0 Sec	98°F	6.8 Sec	≦10 Sec

Except for secondary damage suffered in the failure, the T55-L-713 gas producer turbine components were in good condition and showed relatively little thermal distress.

BACKGROUND

The purpose of the LCF test is to subject the engine, in a short time, to the number of thermal shock cycles it would encounter during an extended period of operation. This LCF test was conducted as part of the T55-L-713 qualification program. This type of test is also imposed on new or redesigned parts (feature items) that are or may be scheduled for inclusion in production engines and which may be sensitive to this type of cycling.

Engine M-11 testing was conducted in accordance with T55-L-713 Experimental Test Specification XTS 512.2.4 (Appendix I). The measured gas temperature ($T_{4.5}$) demonstration requirements were 1650°F at maximum power and 1500°F at maximum continuous power. The engine build contained several qualification components (feature items) that are scheduled for inclusion in the T55-L-714 engine. These were the first stage nozzle, P/N 2-121-430-05; first stage rotor assembly, P/N 2-121-090-42: first stage turbine shroud, P/N 2-141-470-20; second stage nozzle, P/N 2-121-100R72; and gas producer spacer, P/N 2-121-070-30.

The initial 1000-cycle segment of the scheduled 2000-cycle LCF test of this engine was completed in November, 1986. Results of that portion of the test have been reported in Report No. LYC 87-3, which is included as Appendix IV herein. The configuration of the engine for the second 1000 cycles was the same as that for the first segment, with the following two exceptions:

1. The post 1000 cycle inspection revealed a cracked cooling air baffle in the second nozzle. The nozzle was reworked, following approval from appropriate parties, to the 2-121-100-R72 configuration which is the 2-121-100-61 nozzle with the "superflex" baffle. There was no other work done on the second nozzle assembly.

2. A new set of "960 series" (P/N 2-300-96X) measured gas temperature (MGT) harness probes with modified junction boxes were installed. The modification provides for increased clearance between the boxes and the combustor liner. Engine M-11C was built in accordance with test and assembly memorandum number 329-011 included as Appendix II.

TEST EQUIPMENT

A list of test equipment is included in paragraph 4.2 of XTS 512.2.4 contained in Appendix I. The following is a list of specific test equipment utilized for testing:

A. Engine Starting

The system consisted of a Vickers SV-3-150-4 hydraulic starter powered by a hydraulic cart. Pressure was set to 3500-3750 psi. This produces torque approximating the minimum applied torque specified in the PIDS.

B. Vibration

Three C.E.C. vibration pickups, Model No. 4-118, were installed on the engine and monitored during all testing.

C. Transient Recordings

A Gould recorder (oscillograph) was used for transient calibrations and to provide a continuous record of the following parameters.

1. Gas Producer Speed, NI, % of 18,720 rpm
2. Power Turbine Speed
3. Fuel Flow, pounds per hour
4. Measured Gas Temperature, $T_{4.5}$, °F
5. Output Shaft Torque, pound-feet
6. Compressor Discharge Total Pressure, Pt_3, psig
7. Power Lever Angle, degrees

METHOD OF TEST

Testing was conducted in accordance with Military Specification AV-E-8593B, Avco Lycoming Prime Item Development Specification (PIDS) 124.53, Revision B, dated 18 December 1981, and Experimental Test Specification XTS 512.2.4 (Appendix I). Prior to initiation of cycling, the engine was calibrated using MIL-T-5624, Grade JP-4 fuel, and MIL-L-23699 oil. The calibration included power transients and the engine torquemeter system. A performance check was performed after every 100 cycles and a calibration was scheduled for 1500 cycles.

A fuel sample was taken prior to beginning cycling and after the failure.

The engine oil system was drained and refilled with new oil before commencing cycling. A sample of new oil was taken and a second sample of oil was taken from the engine, following completion of the calibrations, for spectrometric analysis. The latter sample is used as a baseline for comparison of later spectrometric oil samples.

Following the scheduled 500-cycle (1500 total cycles) calibration, the engine was removed from the test cell for a brief period to facilitate removal of the combustor/power turbine assembly and GP turbine hardware for hot section inspection.

Oil was added only as needed to replace losses due to normal consumption and sampling. All additions and losses due to sampling or filter removal were recorded on the test log sheets.

New fuel and oil filters were installed before the start of testing. Filter impending bypass indicators (pop-up button) were checked after every four cycles (1 hour of operation). Filter replacement was to be only on actuation of the indicator.

Fuel and oil analyses are included in Appendix III.

TEST RESULTS AND DISCUSSION

A. Performance

A pretest calibration following the reassembly of the engine after the first 1000 cycles was performed to establish a performance baseline that provides a reference for measuring performance changes during and after the endurance testing. A review of figures 1 through 7 shows that the engine met specification performance guarantees at the start of cycling. Pretest (second 1000 cycles) sea level standard day performance at the rated powers was:

POWER RATING	SHP	Wf SPEC	Wf DEMO	$T_{4.5}$ SPEC	$T_{4.5}$ DEMO	NI SPEC	NI DEMO
Emergency	5028	2563	2512	1681	1663	109.9	108.2
Maximum	4818	2438	2410	1621	1604	108.2	106.7
Intermediate	4472	2254	2232	1538	1525	105.6	104.3
Max Continuous	4110	2087	2070	1470	1451	103.4	102.0

Performance data were recorded every fourth cycle (once each hour) at the maximum and maximum continuous power points as a means to track any performance changes that might occur during cycling. Table 2 and Figures 1 through 7 illustrate the performance changes seen from the pretest calibration for the first 1000 cycles through to the 1700 cycle performance check of the second 1000 cycles. The observed degradation is well within that expected for a test of this severity and duration. Based on trends shown by the 100 cycle calibrations, a performance analysis predicts that the engine would have met post test requirements at the completion of 2000 cycles.

Transient times were within specification throughout the test. Pretest and post 1500 cycle times are tabulated below:

	AMB	FI MAX	SPEC	AMB	GI - MAX	SPEC
Pretest	98°F	4.8 sec	4.4-5.0 sec	98°F	6.8 sec	≦10 sec
Post 1500	78°F	4.3 sec	3.8-4.4 sec	78°F	7.9 sec	≦10 sec

There was a total of 814 starts made during this 746-cycle segment of the LCF Test. Of this total, 746 were completed as part of cycling and the remainder for checkouts and calibrations. The average start time was 18.2 seconds with an average peak temperature of 1171°F.

B. Mechanical

Tabulated below are the average actual shaft horsepower (SHP), power turbine inlet temperature ($T_{4.5}$), and gas producer speed (NI, % of 18,720 rpm) demonstrated during the 746 cycles:

	SHP	$T_{4.5}$, °F	NI, %
Maximum	4737	1654	107.2
Max. Continuous	4078	1507	103.3

Oil consumption was negligible as was seal drain leakage.

No chip alarms occurred during pretest operation or cycling. Engine vibrations were continuously monitored during steady state and transient operation. Levels remained constant and within limits throughout testing. There was no increase in levels immediately prior to the engine failure.

Prior to beginning this block of testing, a JFC 31-25 fuel control (S/N A6431) was installed, per AVSCOM request, in place of the JFC 31-22 control. After completion of 127 cycles the -25 control was removed because of several occurrences of hung starts. Visual observation of the bleedband during several starts revealed that the bleedband was partially closing during the start. The bleedband actuator stroke was checked and found to be in specification. The fuel control was replaced with another -25 control (S/N 70533) with the effect of eliminating the hung starts. Because of several observations of torching at ignition during the start sequence, at and just prior to cycle 1357, two start fuel nozzles were inspected and replaced when one was found to be cracked, thus causing excessive flow.

After shutdown on completion of cycle 1401 and several preceding cycles, stack fires occurred. There have been incidents of stack fires reported from the field while operating in conditions similar to those present in the test cell, i.e., high ambient temperatures (80 + °F), with JP-4 fuel. The apparent cause is boiling of the fuel in the heat exchanger which causes fuel to be forced into the combustor after shutdown. A pressurizing valve that prevents this fuel from entering the combustor following a shutdown was installed. This valve has been successfully tested on the ALF 502 engine, on an L-712 in endurance testing, and in a Chinook helicopter at Ft. Rucker. The combustor was inspected with no damage being found. There were no further stack fires.

After completion of 500 cycles (1500 total cycles), a scheduled hot section inspection was performed. The gas producer and power turbine sections were disassembled for visual inspection. No significant discrepancies were observed. Observations noted were as follows: Limited additional combustor distortion; a circumferential 20° braze separation in the second nozzle; and a slight change in the third rotor shroud gap. Overall, all components appeared to be fully capable of completing the last 500 cycles of LCF testing.

One hardware change was made at the 1500 cycle point. Calibration data indicated that the MGT harness probes were reading incorrectly (lower than actual). A new set of probes was installed. Two of these probes required changing after an additional 200 cycles of operation (at 1700 cycles) for the same reason. It should be noted that probe resistance checks (a standard method of checking probe condition) were being made after the scheduled 100 cycle calibrations. It appears that the resistance check is not a reliable indicator of this type of malfunction, although it does detect open or short circuits. Recent investigation has revealed that oxidation of the probe tip (thermocouple) can affect the indications given. This condition is not detectable by the resistance check. A posttest functional check showed the five pairs of probes to be reading an average of 30°F low. An analysis of engine performance data indicated that the harness was indicating from 30°-50°F low while in operation. Oxidation was evident on the tips of all probes.

While operating at maximum power during cycle number 1746, the engine suffered a failure which resulted in the ejection of both power turbines from the engine. There were no prior indications of a developing problem or imminent failure.

To date, investigations have not positively identified the cause of failure. Evidence does appear to support the theory of a third stage (first power turbine) blade failure. However, in the absence of any evidence of initial foreign object damage (F.O.D.), overspeed, overtemperature, fatigue, stress rupture damage, or excessive creep, the cause of a blade failure could not be determined. Investigations are continuing. With the exception of the MGT harness, all components requiring posttest functional tests were found to operate satisfactorily and in no way may have contributed to the failure. The investigation of the failure is documented in Report No. LYC 87-15.

INSPECTION

Because of the failure, there was extensive damage to the combustor and power turbine components. Examinations of those parts and all collected debris were necessarily very thorough and thus conducted by appropriate engineering departments. Detailed reports of their findings have been prepared and published. As stated previously, investigations are centering on identifying a cause of a third stage failure. Based on the posttest inspections and the excellent condition of the above components at the 1500 cycle inspection, it is confidently felt that had there not been a blade failure, the components would have satisfactorily completed the test. Post 1500 cycle and posttest photographs are referenced in the following discussion and included in the "Figures" section of this report.

The featured L-714 components survived the failure, suffering only secondary F.O.D. by ingesting small pieces of debris. The results of their inspection are presented below:

First Nozzle (Segmented) - All vanes were in excellent condition with virtually no evidence of leading edge thermal distress. There was some minor cracking of the outer shroud and curl regions. There were no apparent effects due to the localized "hot spot" regions noted in the combustor liner. Figures 8-11.

First Cylinder - There was evidence of some light tip rubs though tip clearances remained uniform. Figure 12.

First Turbine - Blade condition was excellent. Figures 13-16.

Second Nozzle Assembly - Vane condition was excellent with no evidence of thermal distress. There was some axial cracking of th cylinder and numerous cracks in the sheet metal diaphragm. There was a braze separation at the leading edge of the outer shroud spanning an arc of approximately 20° (Figure 18). The posttest inspection showed no change in the separation. The flex baffle repair gave improved durability over the original configuration. Figures 17-20.

Second Turbine - Blade condition was excellent with no thermal distress evident. Tip clearances remained uniform. Figures 21-24.

The excellent condition of the preceding feature items indicates it is highly probable that these feature items would have successfully completed the 2000 LCF cycles.

Listed below are several additional major components accompanied by a description of their condition at the post 1500 cycle and posttest inspections.

Engine Overall - 2 o'clock position, pretest. Figure 25.

Engine Overall - Posttest damage. Figures 26-28.

Compressor Overall - Very good condition at both inspections. Figure 29.

Compressor Housing and Stators - Both items were in very good condition at the inspections. Figure 30.

Third Nozzle Assembly - The nozzle and cylinder were in excellent condition after 1500 cycles. The posttest inspection showed there was very little change in parts condition. There was some secondary damage from the failure. Figures 31-33.

Third Turbine and Power Shaft - There were no significant discrepancies noted at the post 1500 cycle inspection. As the photographs show, posttest damage was extensive. Regarding the blades, there was no evidence of radial pull out from the disc or fatigue on non damaged fractures. Separation of most blades was by impact/bending. Some blades were displaced axially though of the remaining blades in the disc, none were found to be loose. The separation of the power shaft forward of the disc, near the weld interface was the result of axial/torsional tensile overload. Separation forward of the weld is radial tensile (impact/bending). The separation forward of the aft inertia weld was primarily axial with a torsional component (all tensile). Figures 34-39.

Fourth Turbine - The fourth turbine was in excellent condition after 1500 cycles. The failure resulted in the loss of all blades due to tensile impact overload (secondary). All blades were contained by the containment ring. The forward and aft separations on the disc (Figures 41 & 43) were the result of tensile overload with axial, circumferential, and bending components. Figures 40-43.

Fourth Nozzle Assembly - The assembly was in very good condition after completing 1500 cycles. In the failure sequence, the assembly separated from the engine. This was the result of circumferentially sheared forward flange bolts and a shear separation of the nozzle aft of the seam weld. The seam weld is acceptable. Figures 44-46.

Exit Stator Ring - The stator ring was in excellent condition after completing 1500 cycles. The ring remained attached to the fourth nozzle assembly after assembly separation. The fourth stage blades were contained by the ring. Figures 46-48.

Number 4 and 5 Bearing Package - Data taken during testing shows that the 4 and 5 bearing package was operating normally right up to the failure. The package was separated from the engine because of failure of its supports due to axial and shear tensile overload. All bearing damage was secondary. Figures 49 & 50.

Combustor Liner - The liner completed 1500 cycles in very good condition overall. There was some cracking in several panels and the "fish hook". Figure 51.

A notable discrepancy was five "bumps" that formed during testing. Figures 51-53. They coincide with the location of the five MGT harness junction boxes and were first noticed during the post 500 cycle inspection. The bumps and cracks increased slightly by the end of 1000 cycles. Observations made at the 1500 cycle inspection and during the MGT probe replacement at 1700 cycles revealed little change. It is felt these are a result of the higher operating temperatures for this test and a restriction of the cooling airflow, in that area, by the junction boxes; their presence was not deleterious to engine durability and operation.

CONCLUSIONS

1. The engine successfully completed 1745 cycles of a scheduled 2000 cycles.

2. The engine suffered a third stage blade failure.

3. In the absence of any evidence of initial F.O.D overspeed, fatigue, stress rupture damage, or excessive creep, the cause of the third stage blade failure has not been identified.

4. Post 1500 cycle and posttest inspections indicate that the unique L-713/L-714 gas producer hardware would have successfully completed 2000 cycles.

5. The pressurizing valve effectively eliminates post shutdown stack fires.

RECOMMENDATIONS

1. Strong consideration should be given to accepting the premise that the unique L-713/L-714 components would have satisfactorily completed 2000 LCF cycles. This is based on the excellent condition of the subject components at the post 1500 cycle inspection, post failure inspection, and previous observations of component deterioration between 1500 and 2000 cycles.

2. The effectiveness of the pressurizing valve in eliminating post shutdown stack fires during this LCF test provides additional support for acceptance of Engineering Change Proposal (ECP) LY-GT-55-287. The ECP proposes addition of the valve to current and future T55 engines.

TABLE 1
AVERAGE MECHANICAL DATA FROM
LCF TESTING OF ENGINE M-11

	CYCLES COMPLETED	SHP	$T_{4.5}$,°F	NI,%	TIME @ POWER,HR
M-11B					
Maximum	1000	4714	1654	108.5	41.67
Max Continuous	1000	3975	1506	104.3	41.67
M-11C					
Maximum	745	4737	1654	107.2	31.0
Max Continuous	745	4078	1507	103.3	31.0

TABLE 2
PRE FIRST 1000 CYCLES VS. POST 1700 CYCLES
PERFORMANCE

SHP			Wf.LB/HR	
	PRE	POST	Δ	%Δ
5028	2481	2524	+43	+1.7
4818	2355	2421	+66	+2.8
4472	2190	2253	+63	+2.9
4110	2025	2087	+52	+3.1

SHP			$T_{4.1}$.°F	
	PRE	POST	Δ	%Δ
5028	2103	2165	+62	+3.0
4818	2038	2094	+56	+2.8
4472	1949	1997	+48	+2.5
4110	1864	1912	+48	+2.6

SHP			$T_{4.5}$.°F	
	PRE	POST	Δ	%Δ
5028	1641	1673	+32	+2.0
4818	1586	1615	+29	+1.8
4472	1508	1538	+30	+2.0
4110	1436	1470	+34	+2.4

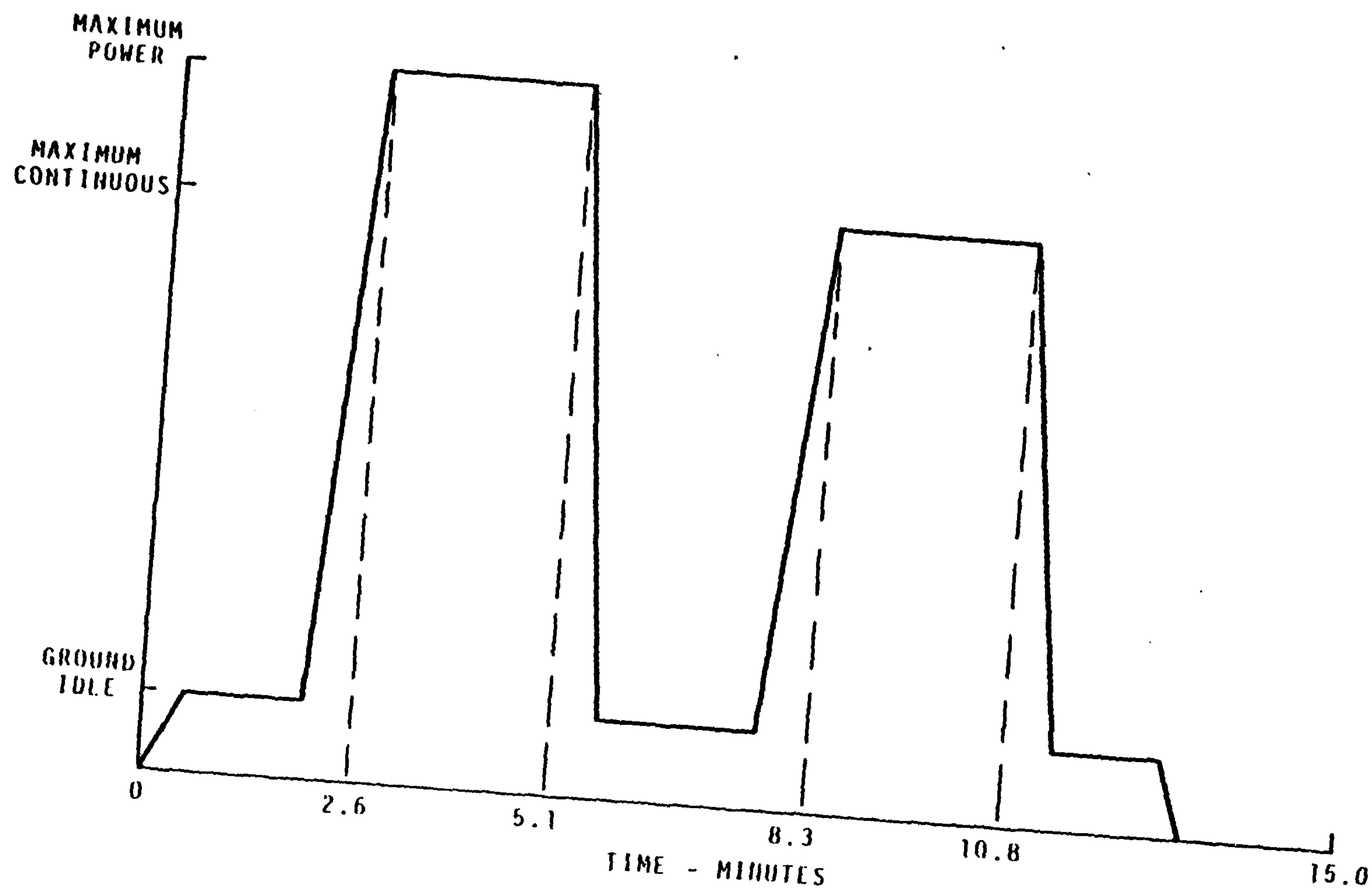
SHP			NI.%	
	PRE	POST	Δ	%Δ
5028	108.9	108.2	-.7	-.64
4818	107.3	106.7	-.6	-.56
4472	104.8	104.3	-.5	-.48
4110	102.3	102.0	-.3	-.29

LE

T55-L-713

LOW CYCLE THERMAL FATIGUE TEST

(ONE CYCLE)



AVCO LYCOMING DIVISION
STRATFORD, CONN.

FIGURES

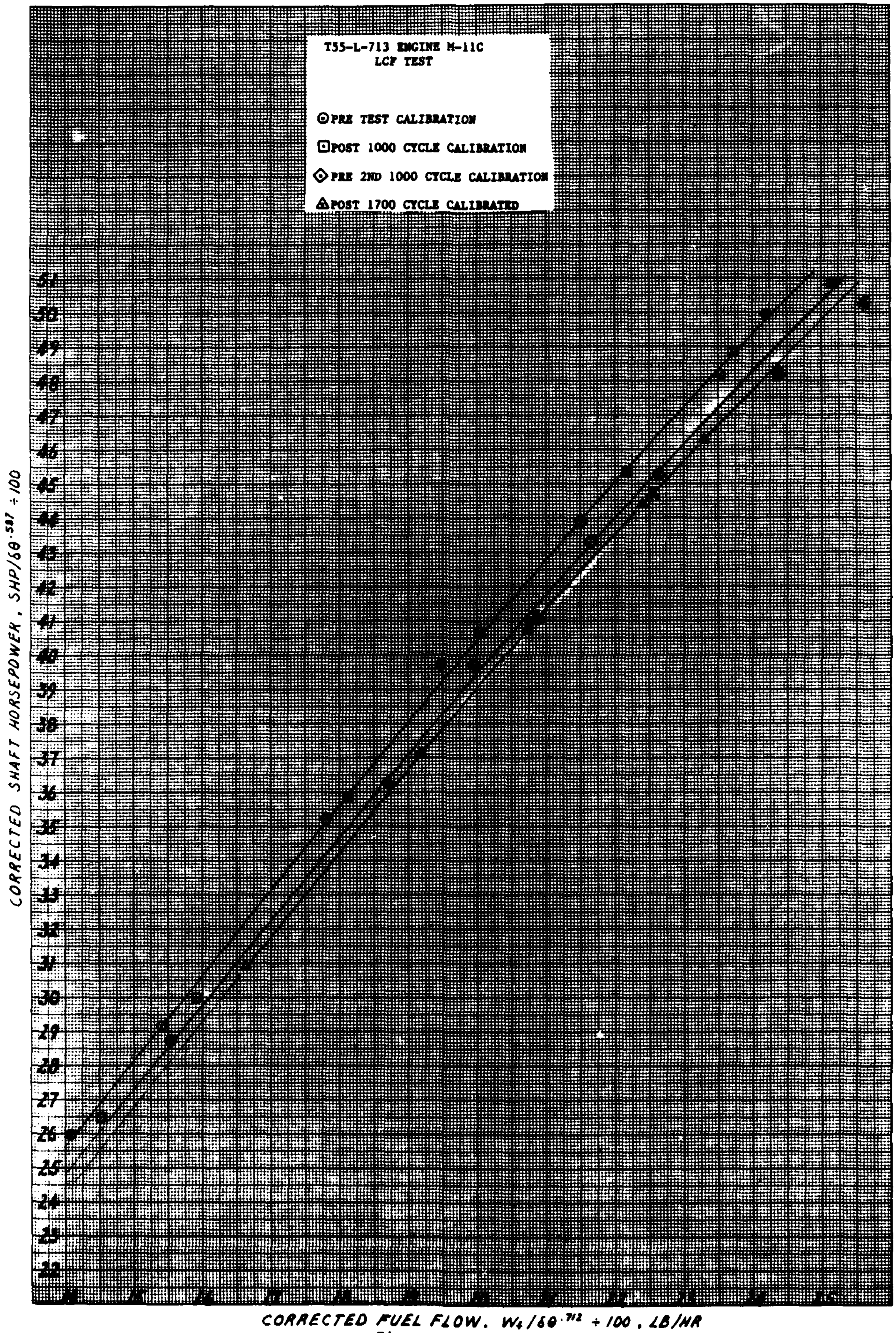

T55-L-713 ENGINE M-11C
LCF TEST
PRE TEST CALIBRATION
POST 1000 CYCLE CALIBRATION
PRE 2ND 1000 CYCLE CALIBRATION
POST 1700 CYCLE CALIBRATED
CORRECTED SHAFT HORSEPOWER, SHP/δθ^.587 ÷ 100
CORRECTED FUEL FLOW. Wf/δθ^.712 ÷ 100, LB/HR

Figure No. 1

K•E 10 X 10 TO THE INCH • 10 X 15 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 47 0780

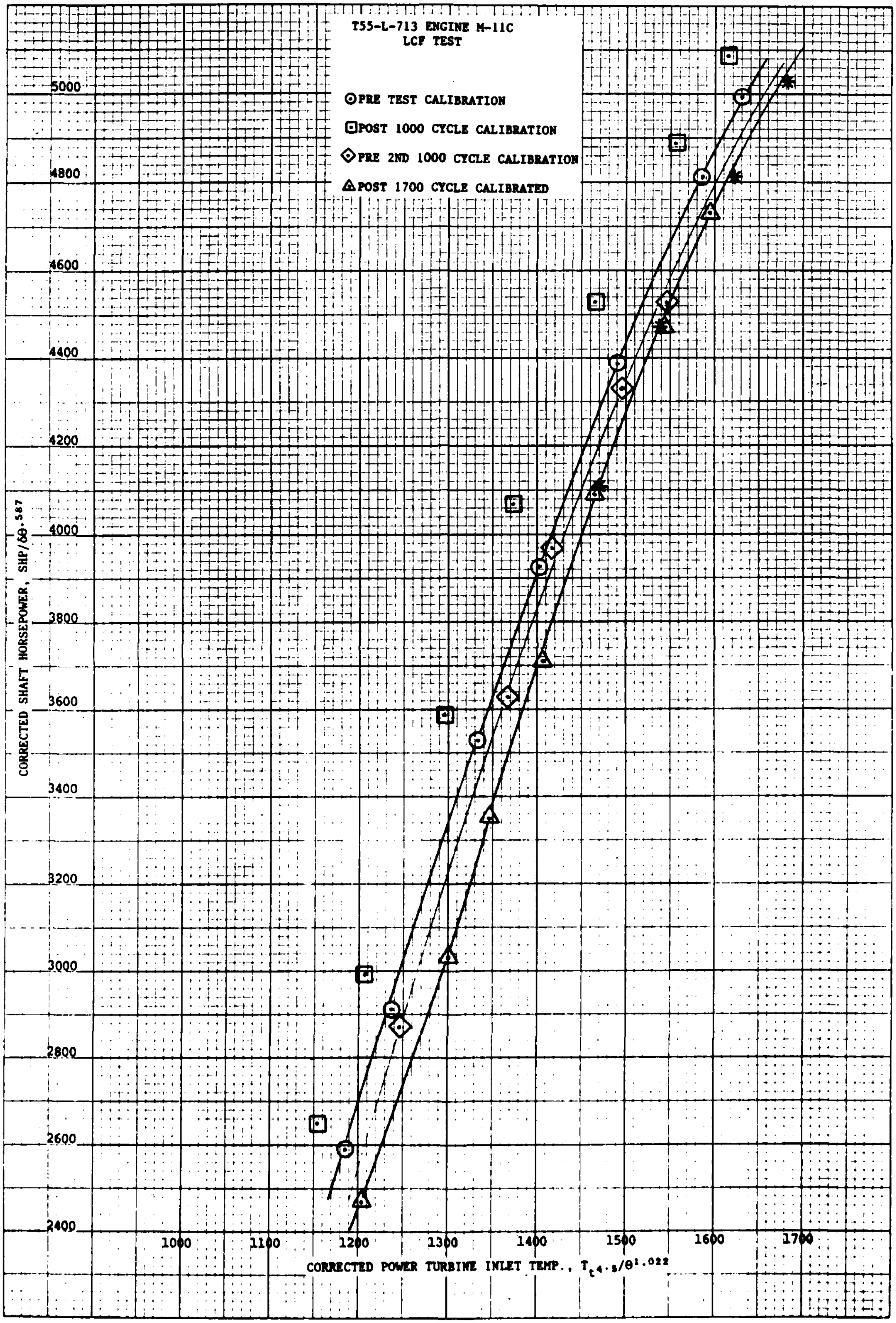


Figure No. 2

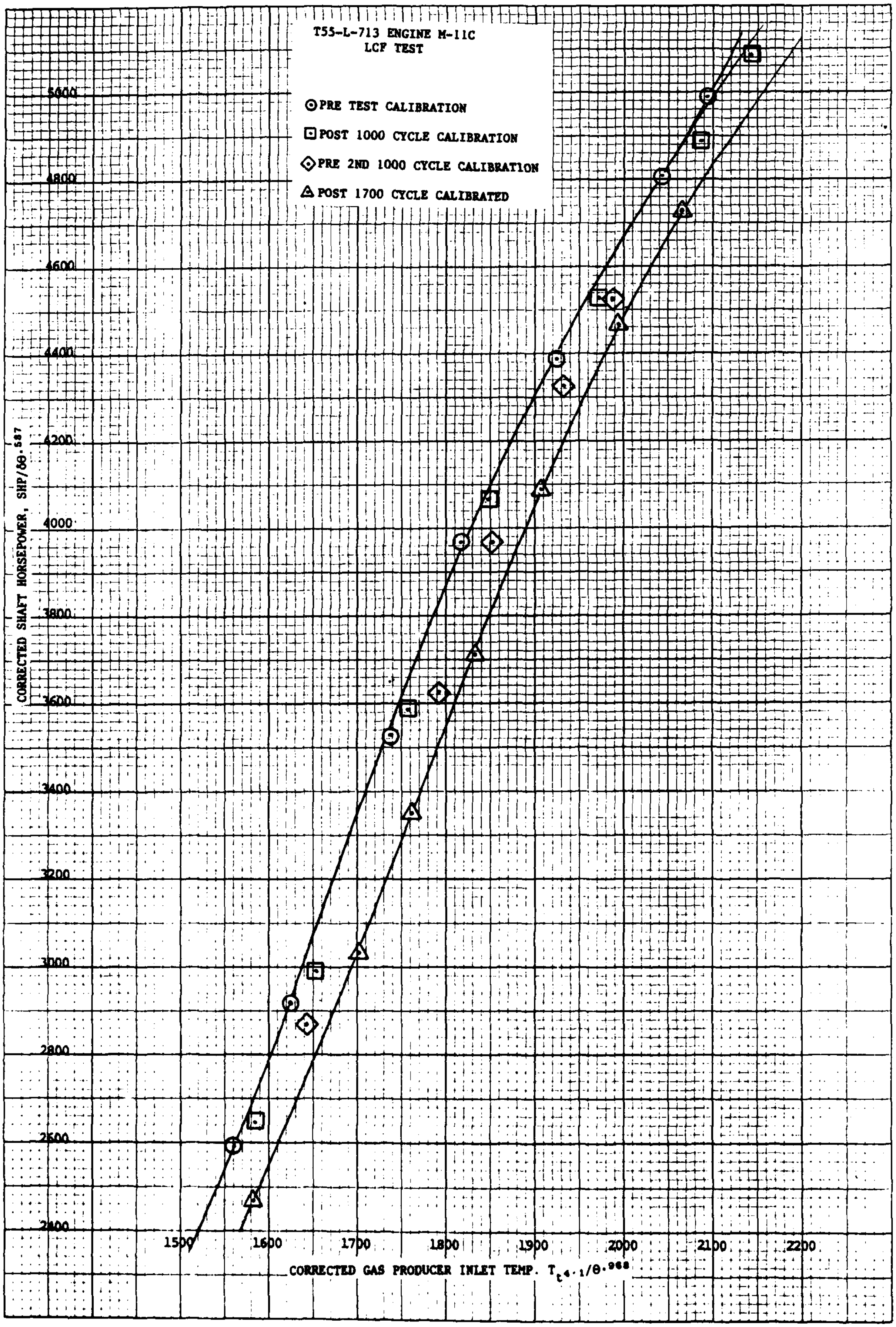

T55-L-713 ENGINE M-11C
LCF TEST
PRE TEST CALIBRATION
POST 1000 CYCLE CALIBRATION
PRE 2ND 1000 CYCLE CALIBRATION
POST 1700 CYCLE CALIBRATED
CORRECTED SHAFT HORSEPOWER, SHP/δθ.587
5000
4800
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
2600
2400
1500
1600
1700
1800
1900
2000
2100
2200
CORRECTED GAS PRODUCER INLET TEMP. T t4.1/θ.968

Figure No. 3

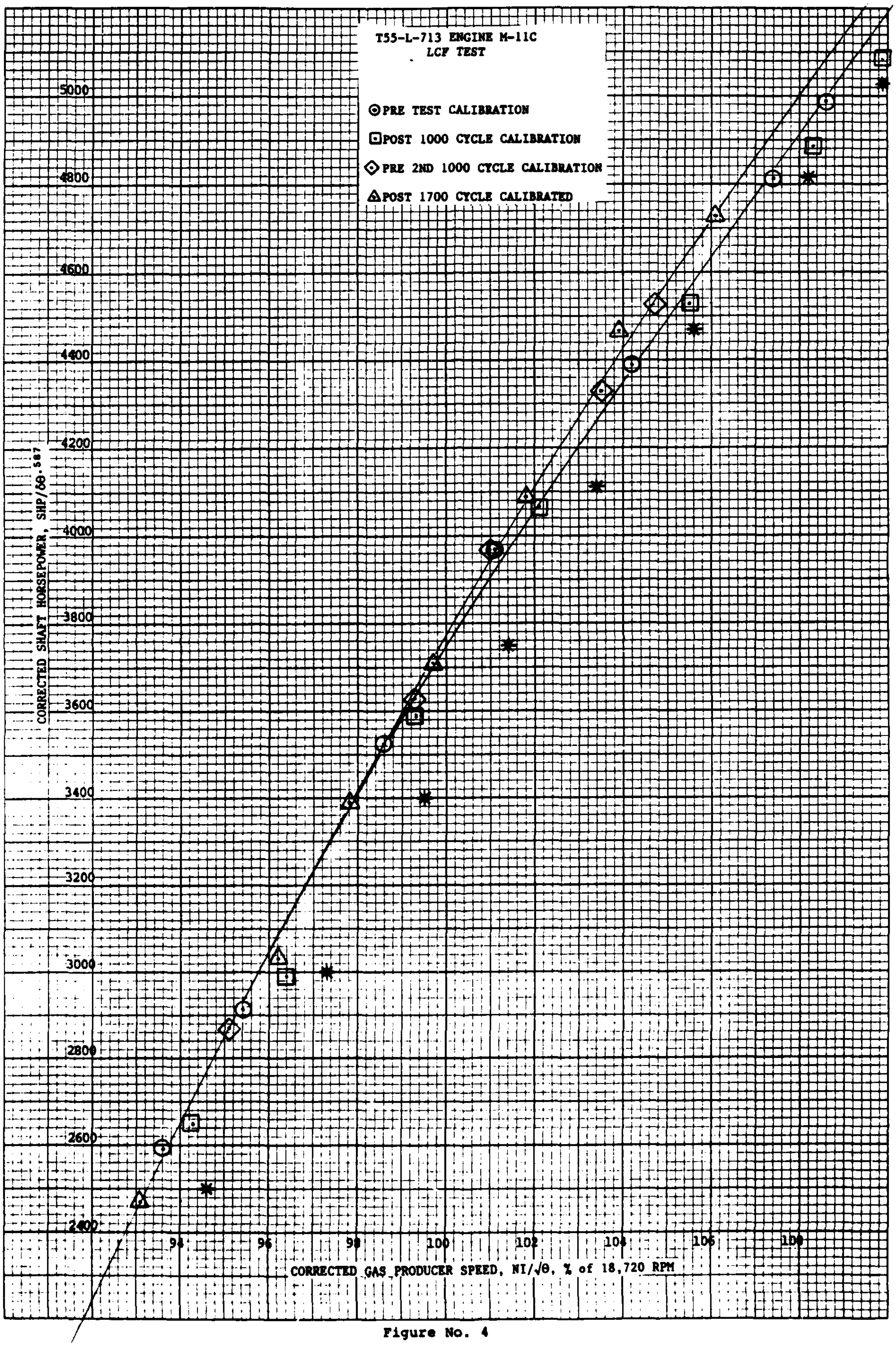

T55-L-713 ENGINE M-11C
LCF TEST
PRE TEST CALIBRATION
POST 1000 CYCLE CALIBRATION
PRE 2ND 1000 CYCLE CALIBRATION
POST 1700 CYCLE CALIBRATED
CORRECTED SHAFT HORSEPOWER, SHP/δθ·587
5000
4800
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
2600
2400
94
96
98
100
102
104
106
108
CORRECTED GAS PRODUCER SPEED, N1/√θ, % of 18,720 RPM

Figure No. 4

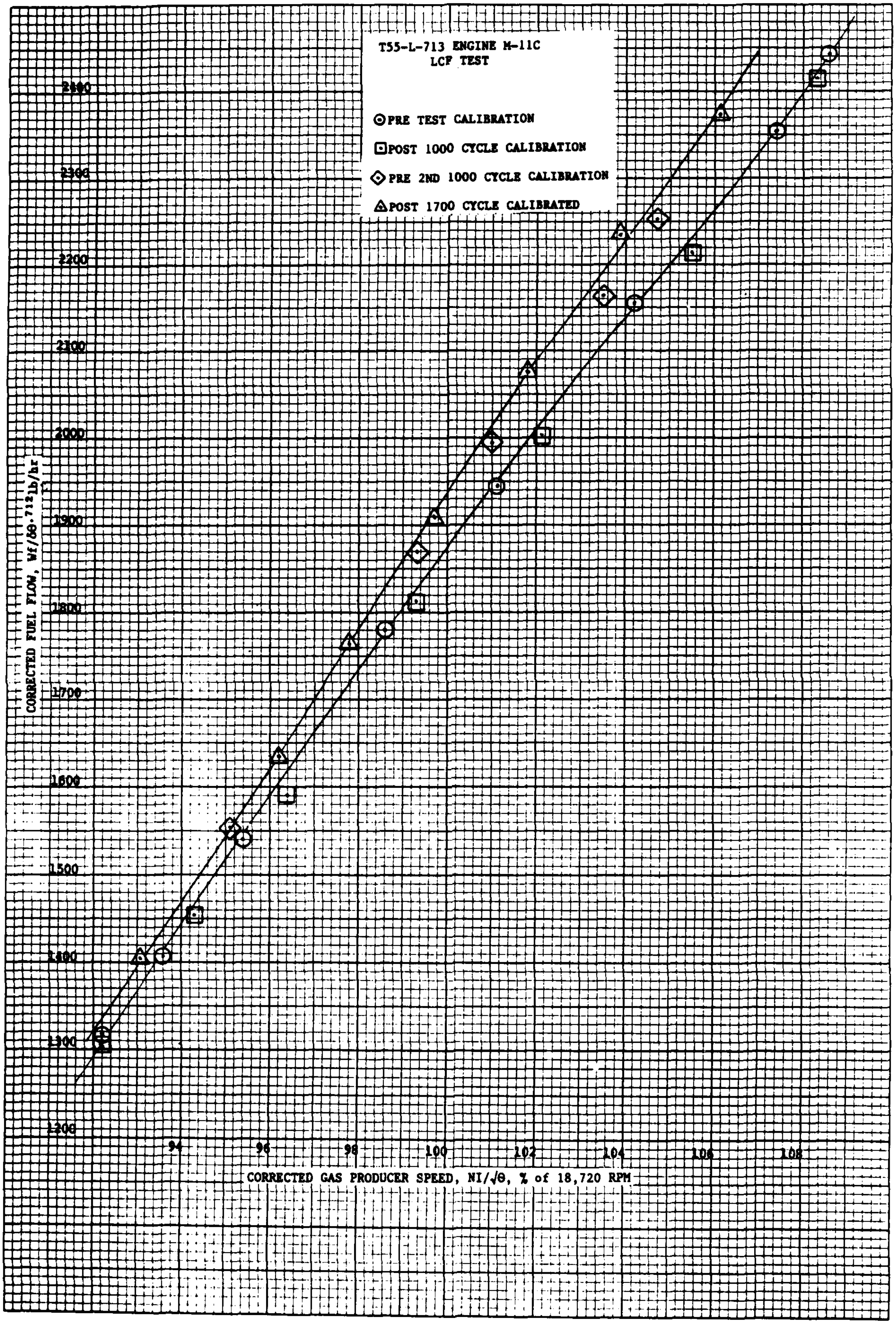

T55-L-713 ENGINE M-11C
LCF TEST
PRE TEST CALIBRATION
POST 1000 CYCLE CALIBRATION
PRE 2ND 1000 CYCLE CALIBRATION
POST 1700 CYCLE CALIBRATED
CORRECTED FUEL FLOW, Wf/δθ·712 lb/hr
CORRECTED GAS PRODUCER SPEED, NI/√θ, % of 18,720 RPM
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
94
96
98
100
102
104
106
108

Figure No. 5

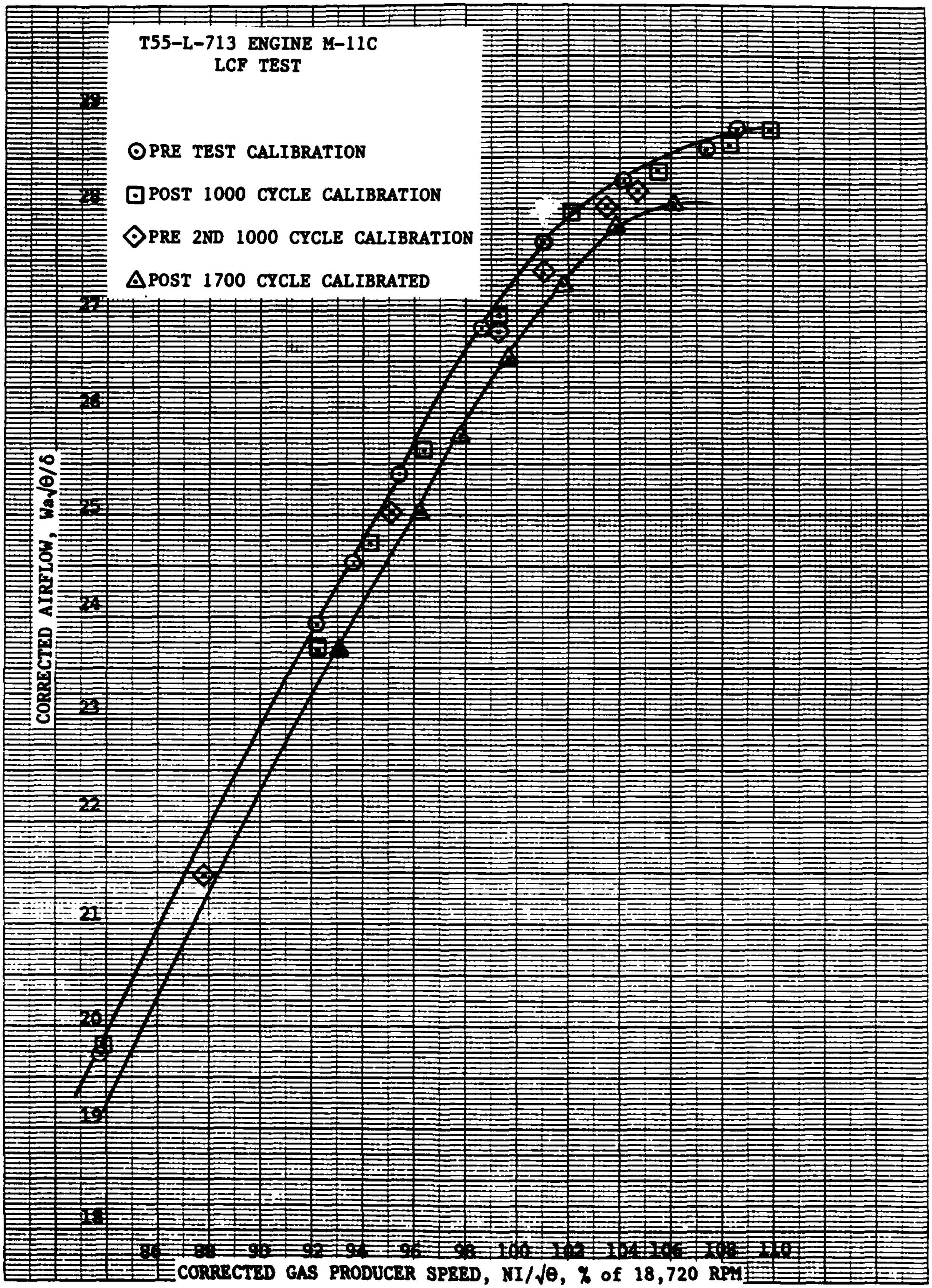

T55-L-713 ENGINE M-11C
LCF TEST
PRE TEST CALIBRATION
POST 1000 CYCLE CALIBRATION
PRE 2ND 1000 CYCLE CALIBRATION
POST 1700 CYCLE CALIBRATED
CORRECTED AIRFLOW, Wa√θ/δ
19
20
21
22
23
24
25
26
27
28
29
86
88
90
92
94
96
98
100
102
104
106
108
110
CORRECTED GAS PRODUCER SPEED, NI/√θ, % of 18,720 RPM

Figure No. 6

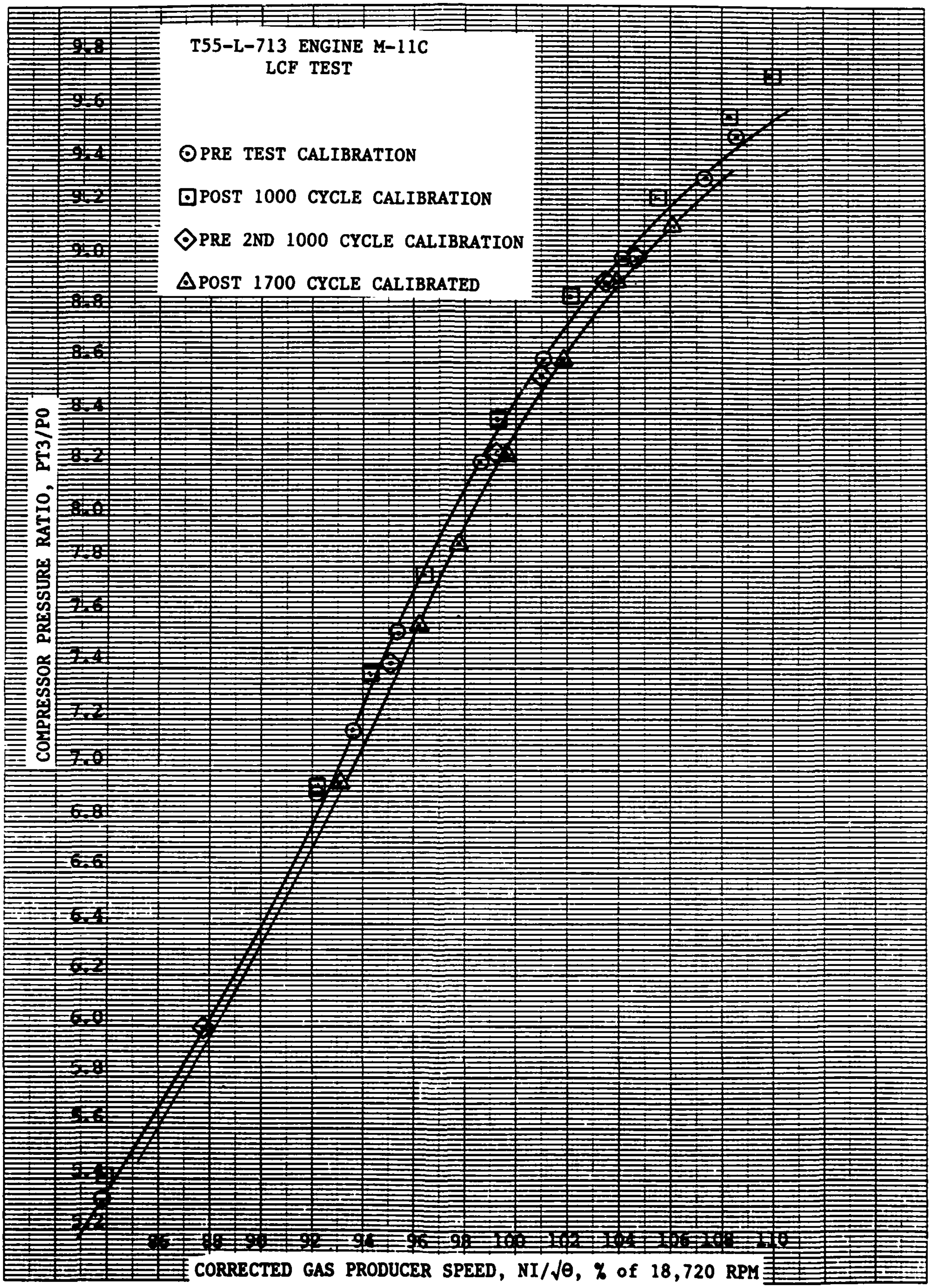

T55-L-713 ENGINE M-11C
LCF TEST
PRE TEST CALIBRATION
POST 1000 CYCLE CALIBRATION
PRE 2ND 1000 CYCLE CALIBRATION
POST 1700 CYCLE CALIBRATED
COMPRESSOR PRESSURE RATIO, PT3/P0
9.8
9.6
9.4
9.2
9.0
8.8
8.6
8.4
8.2
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
6.2
6.0
5.8
5.6
5.4
5.2
86
88
90
92
94
96
98
100
102
104
106
108
110
CORRECTED GAS PRODUCER SPEED, NI/√θ, % of 18,720 RPM

Figure No. 7

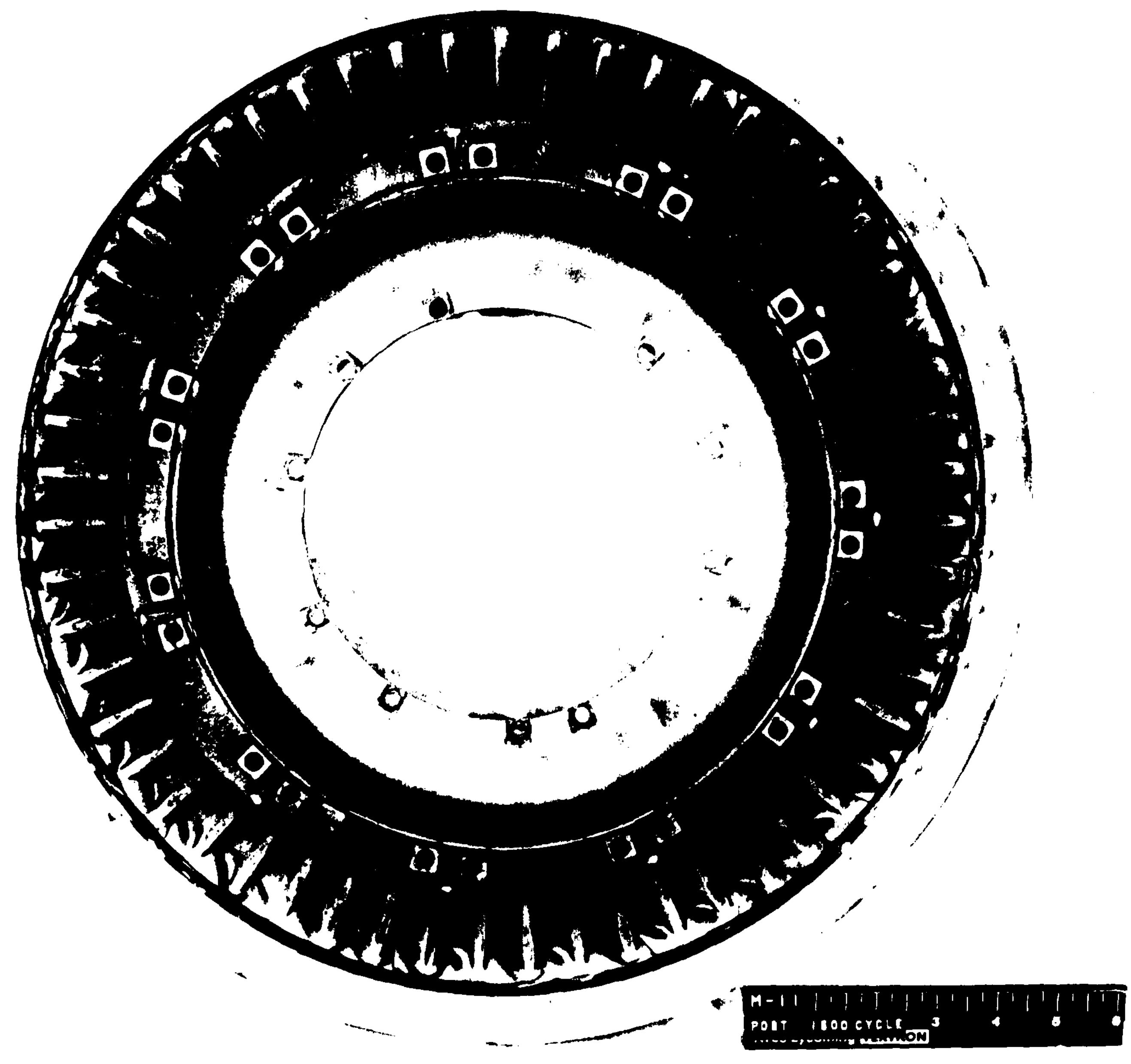


Figure 8 First Nozzle, Front, Post 1500

Figure 8A First Nozzle, Closeup, Curl Crack and Outer Shroud Cracking, Post 1500

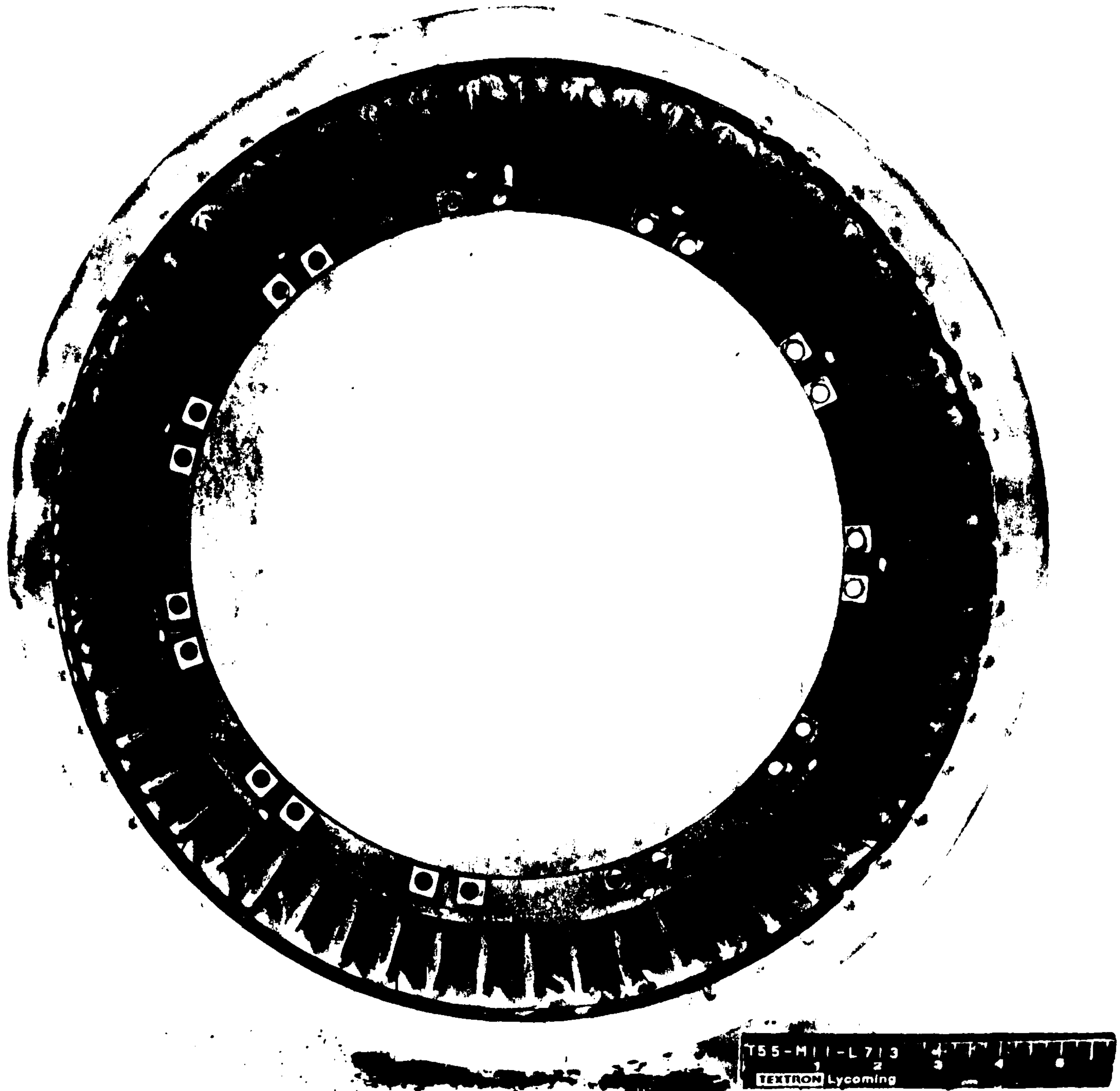


Figure 9 First Nozzle, Front, Posttest

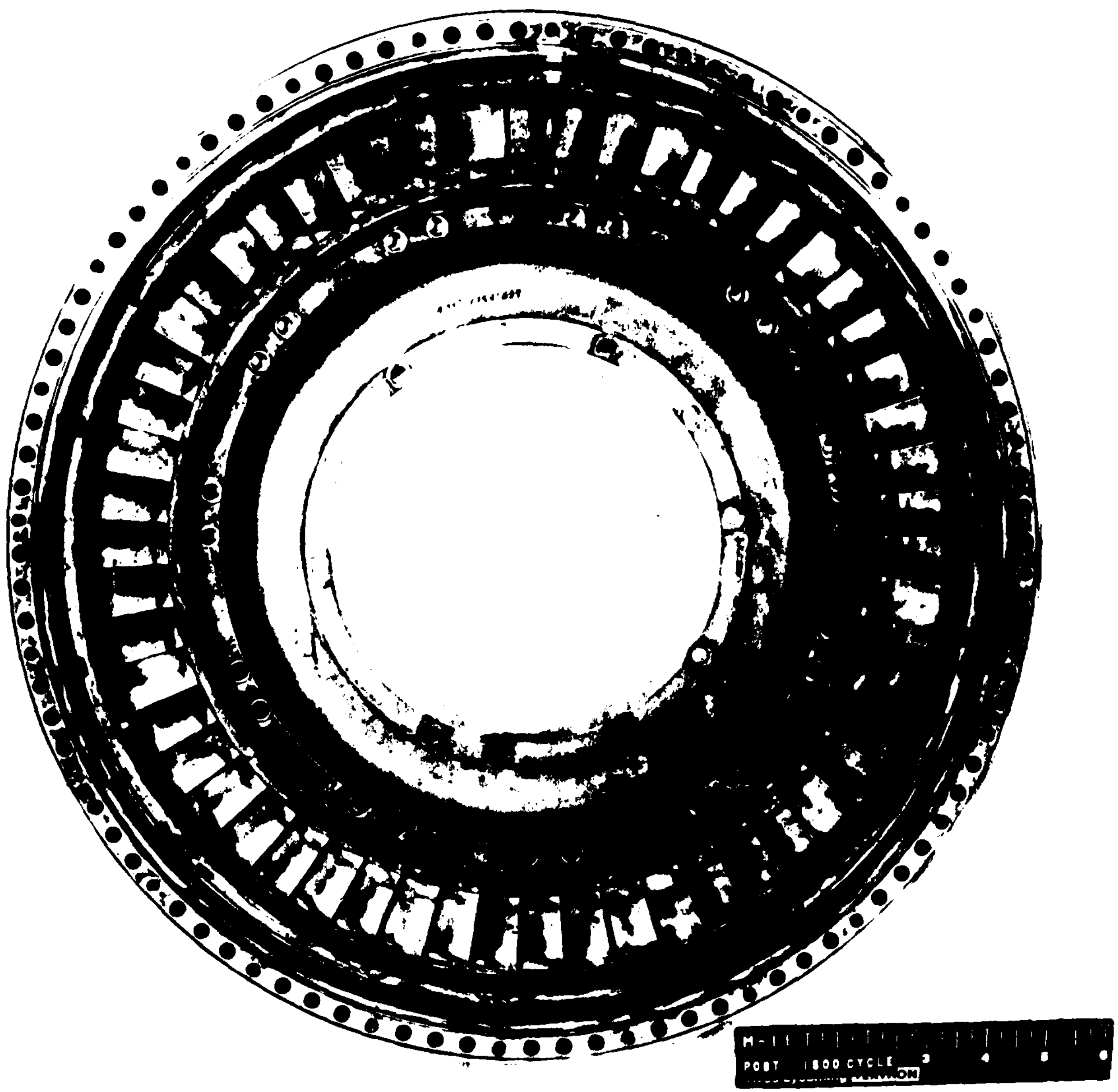


Figure 10 First Nozzle, Rear, Post 1500

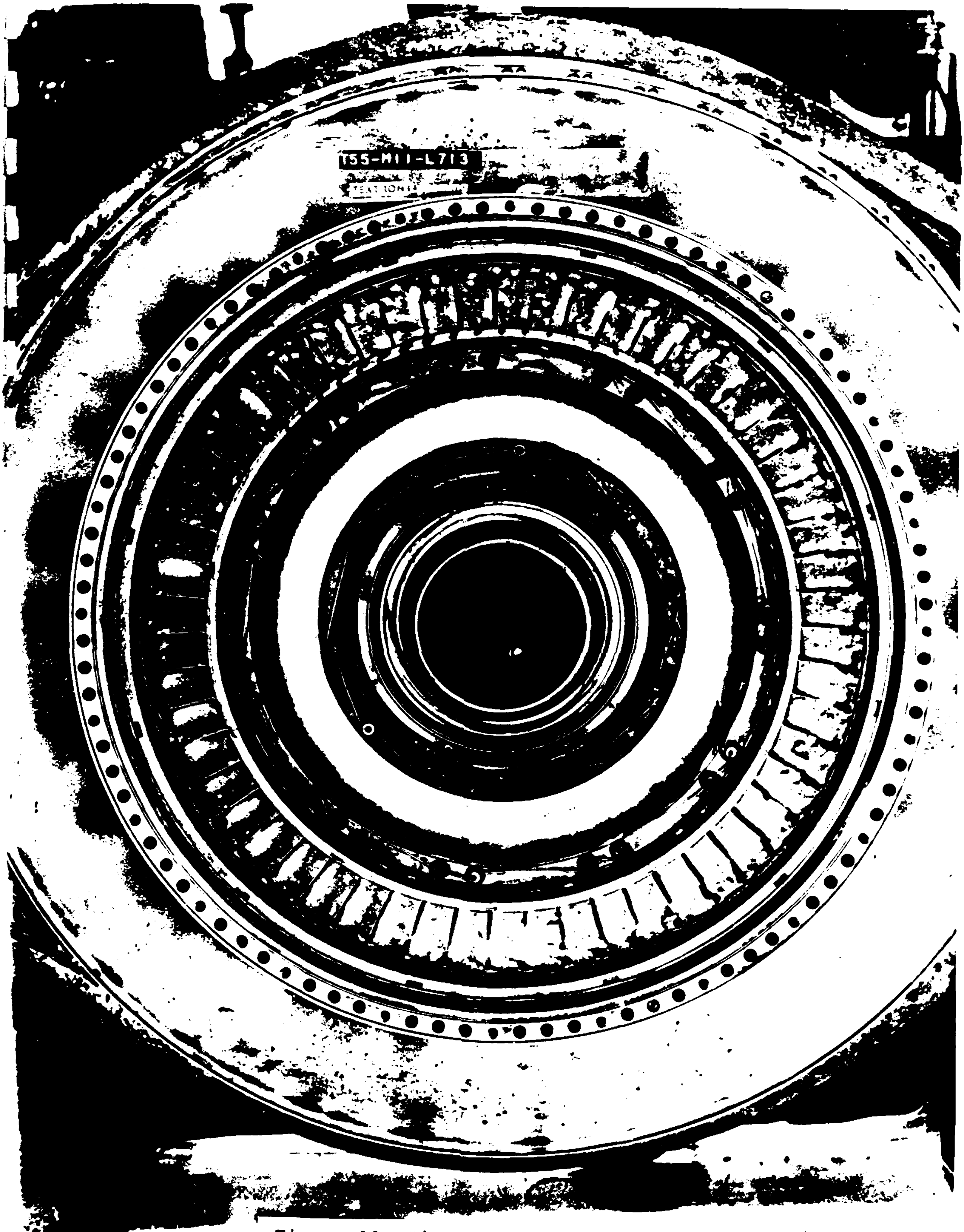


Figure 11 First Nozzle, Rear, Posttest

Figure 12 First Nozzle and Cylinder, Tip Rub and Outer Shroud Cracking, Posttest

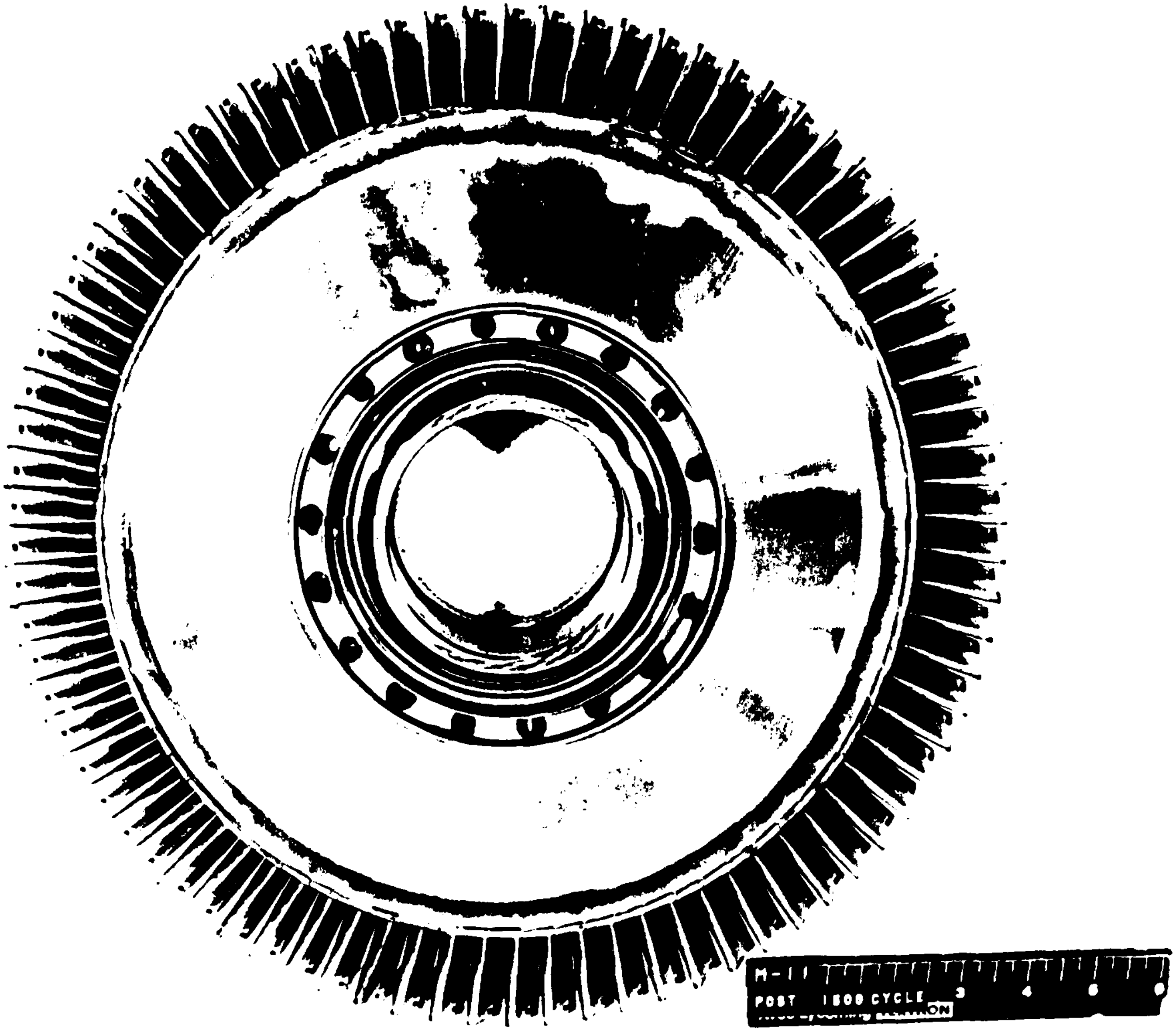


Figure 13 First Turbine, Front, Post 1500

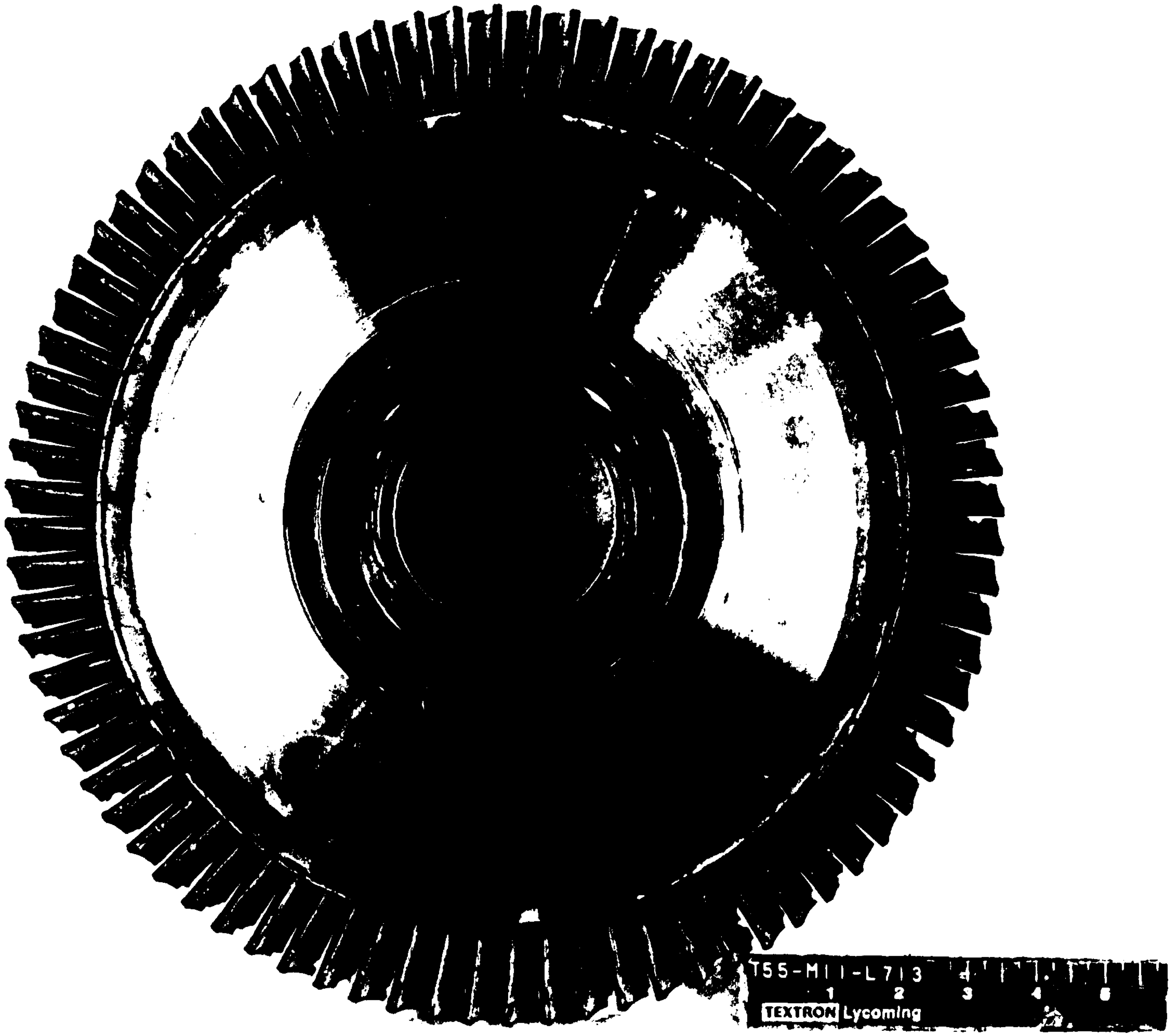


Figure 14 First Turbine, Front, Posttest

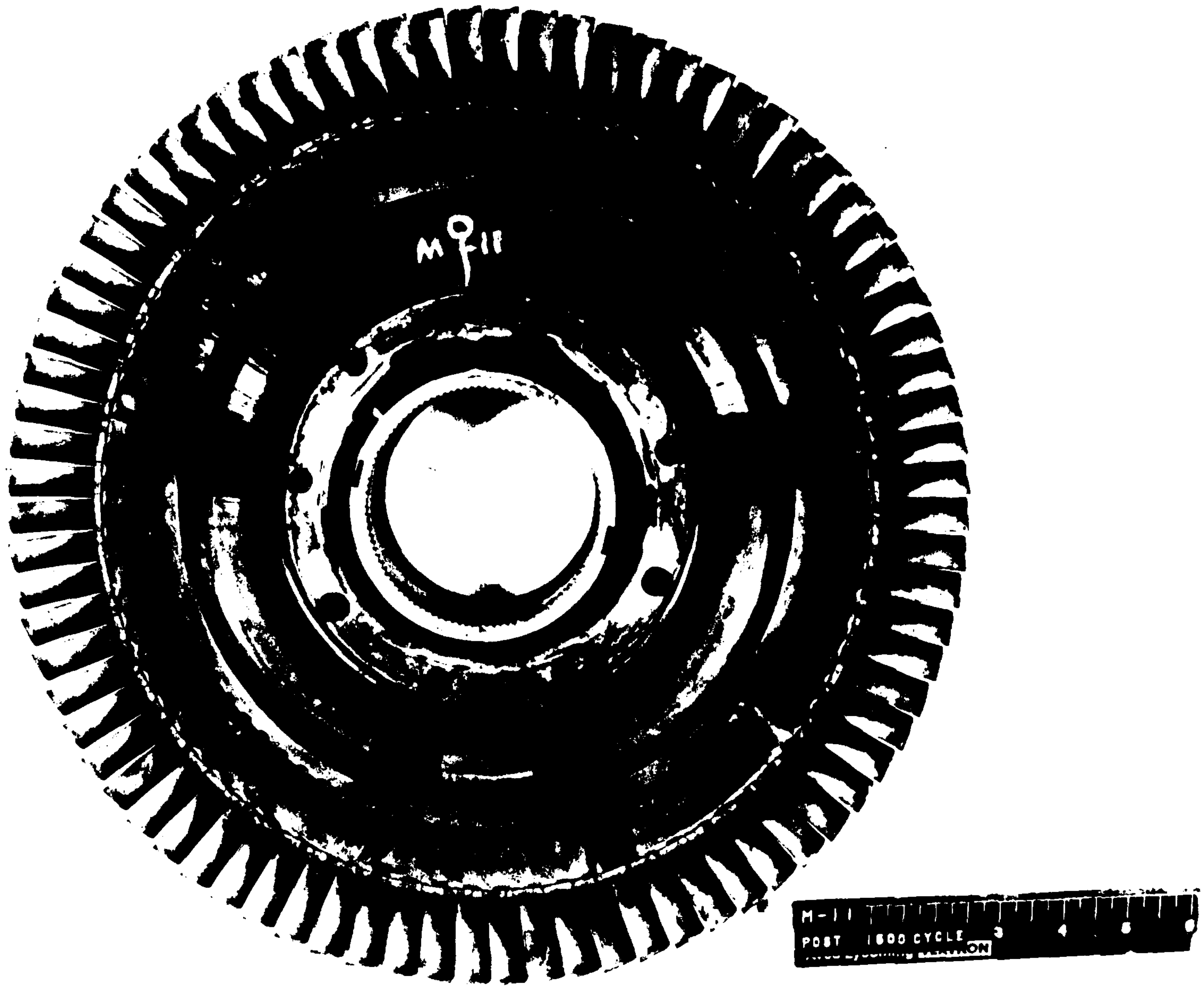


Figure 15 First Turbine, Rear, Post 1500

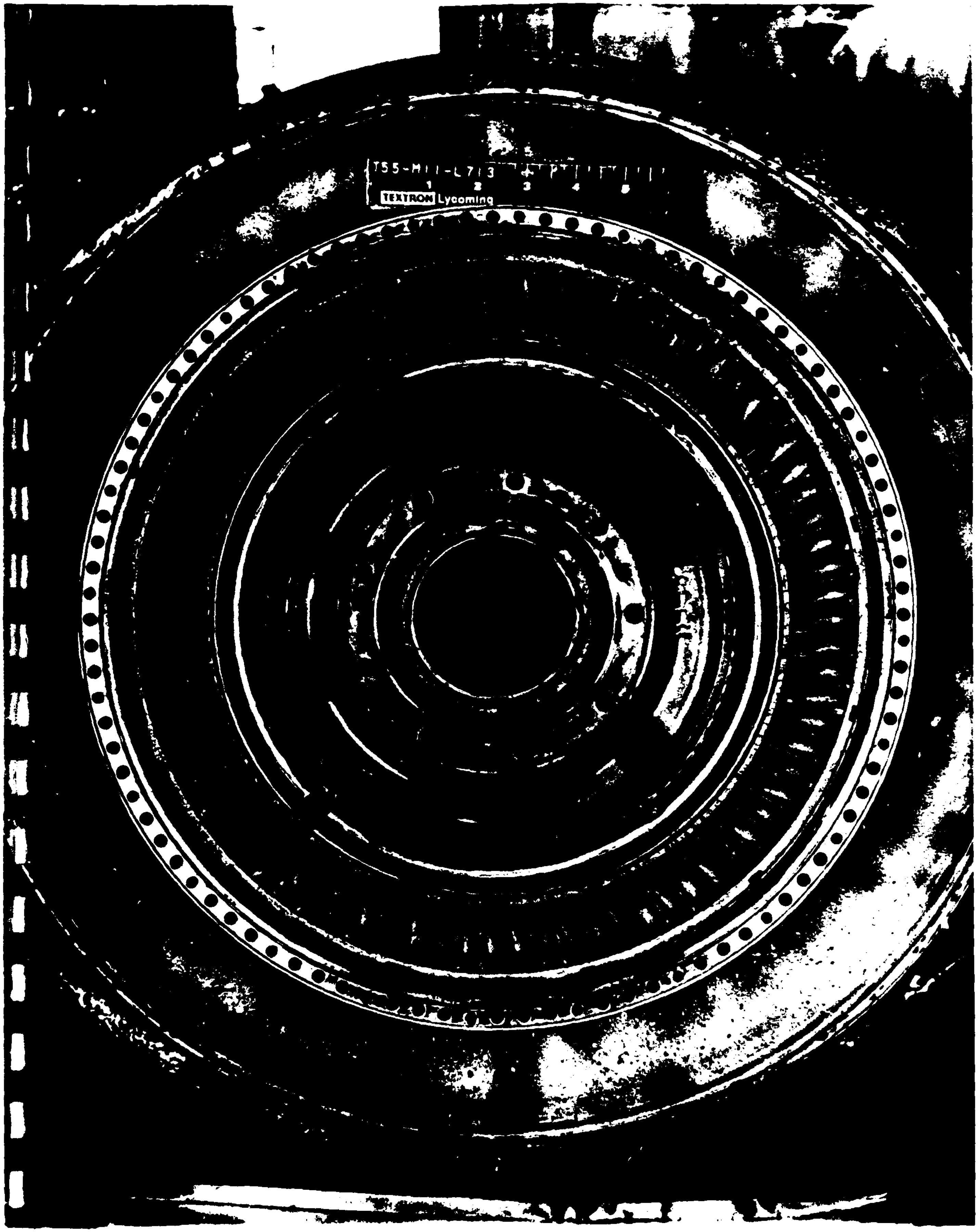


Figure 16 First Turbine and Combustor Curl, Posttest

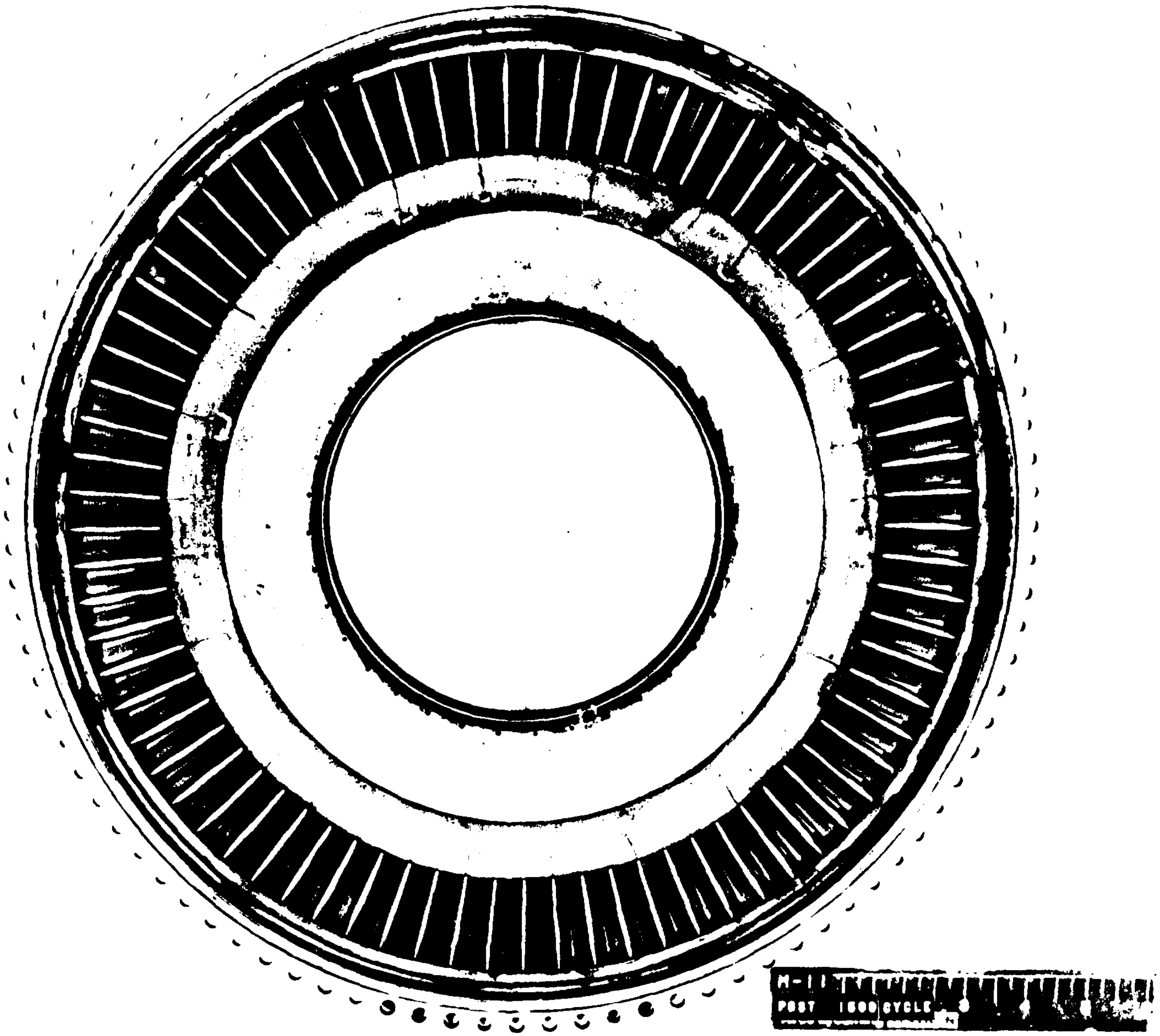


Figure 17 Second Nozzle, Front, Inner and Outer Shroud Cracking, Post 1500

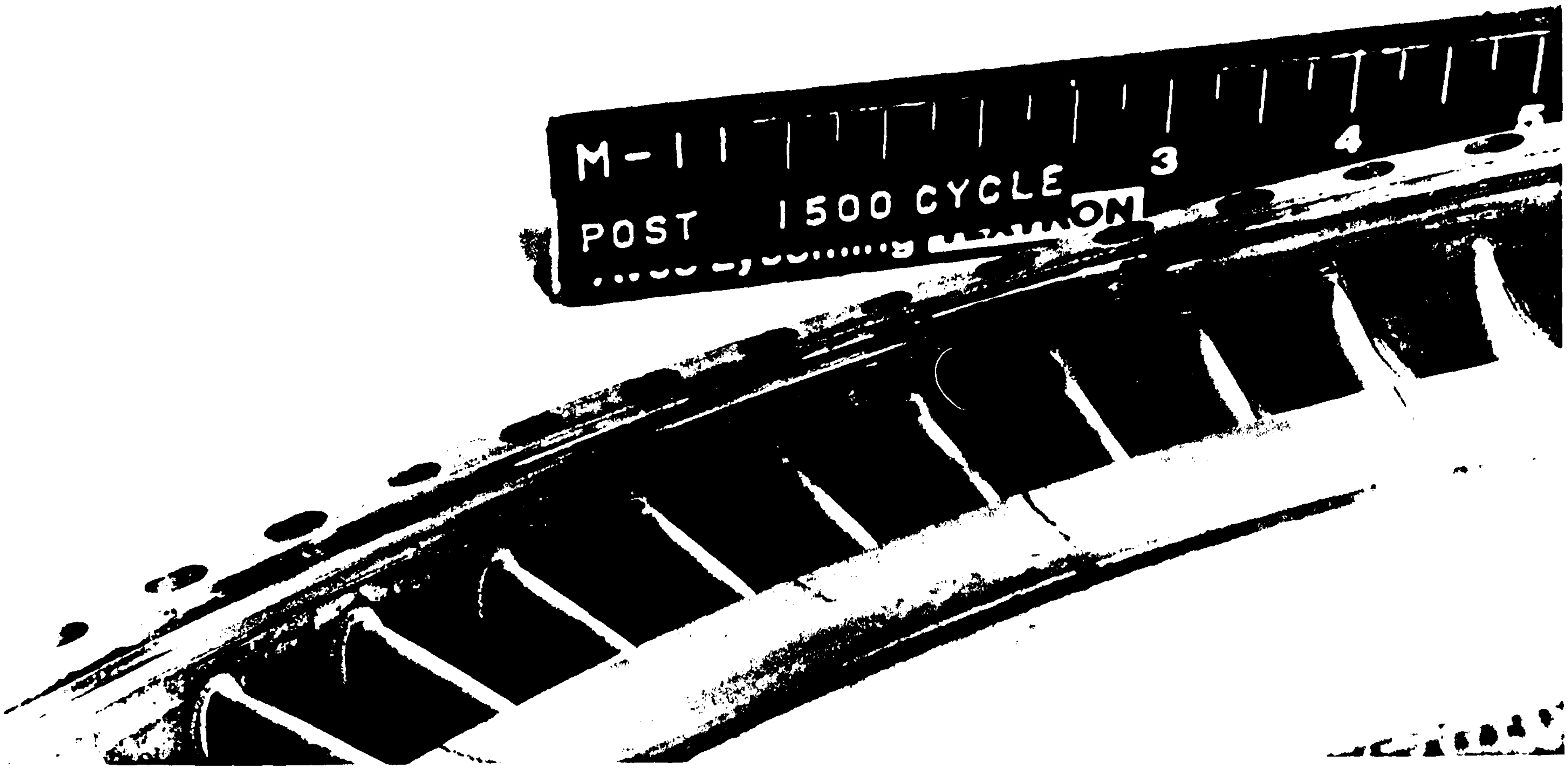


Figure 18 Second Nozzle, Braze Separation, Post 1500

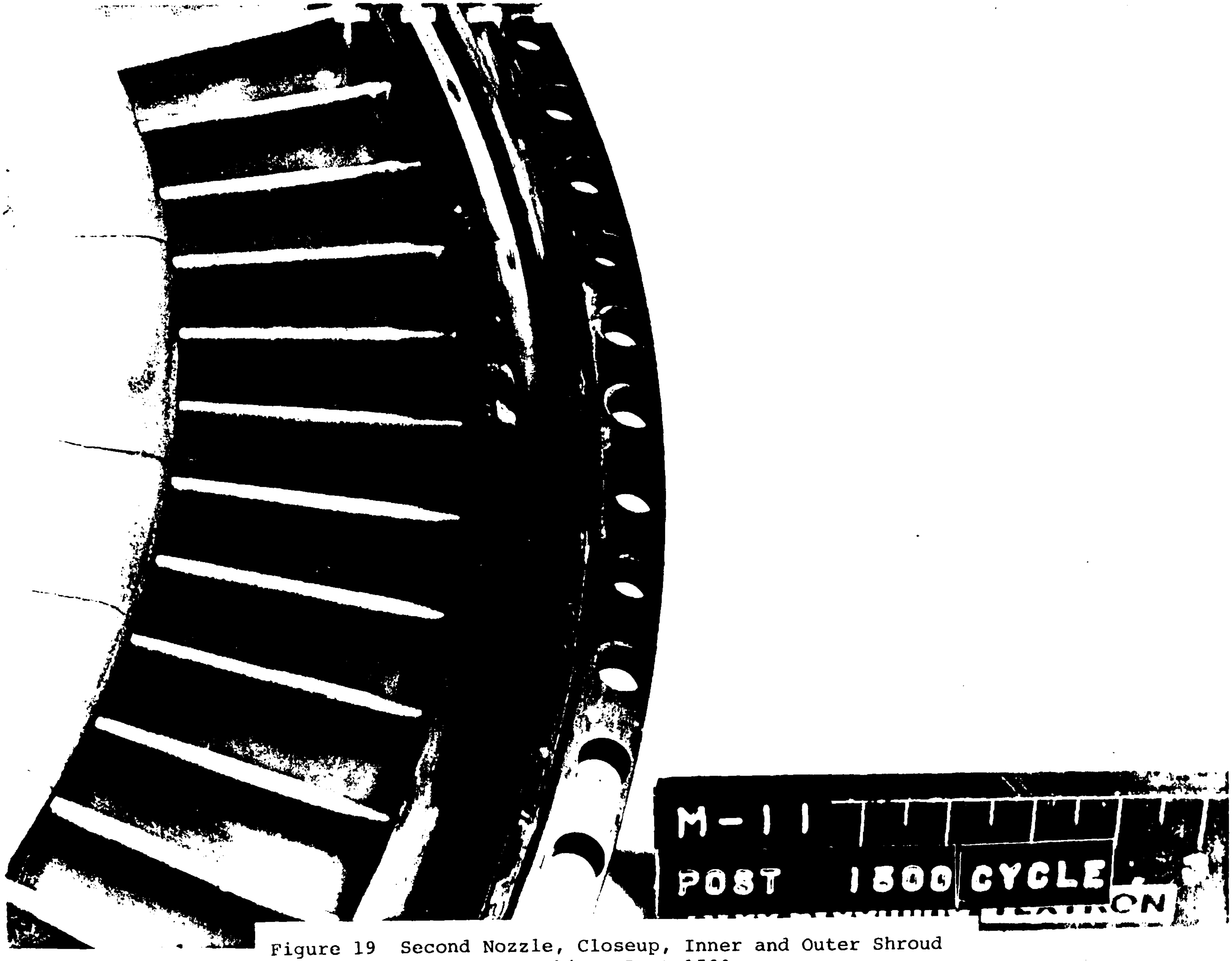


Figure 19 Second Nozzle, Closeup, Inner and Outer Shroud Cracking, Post 1500

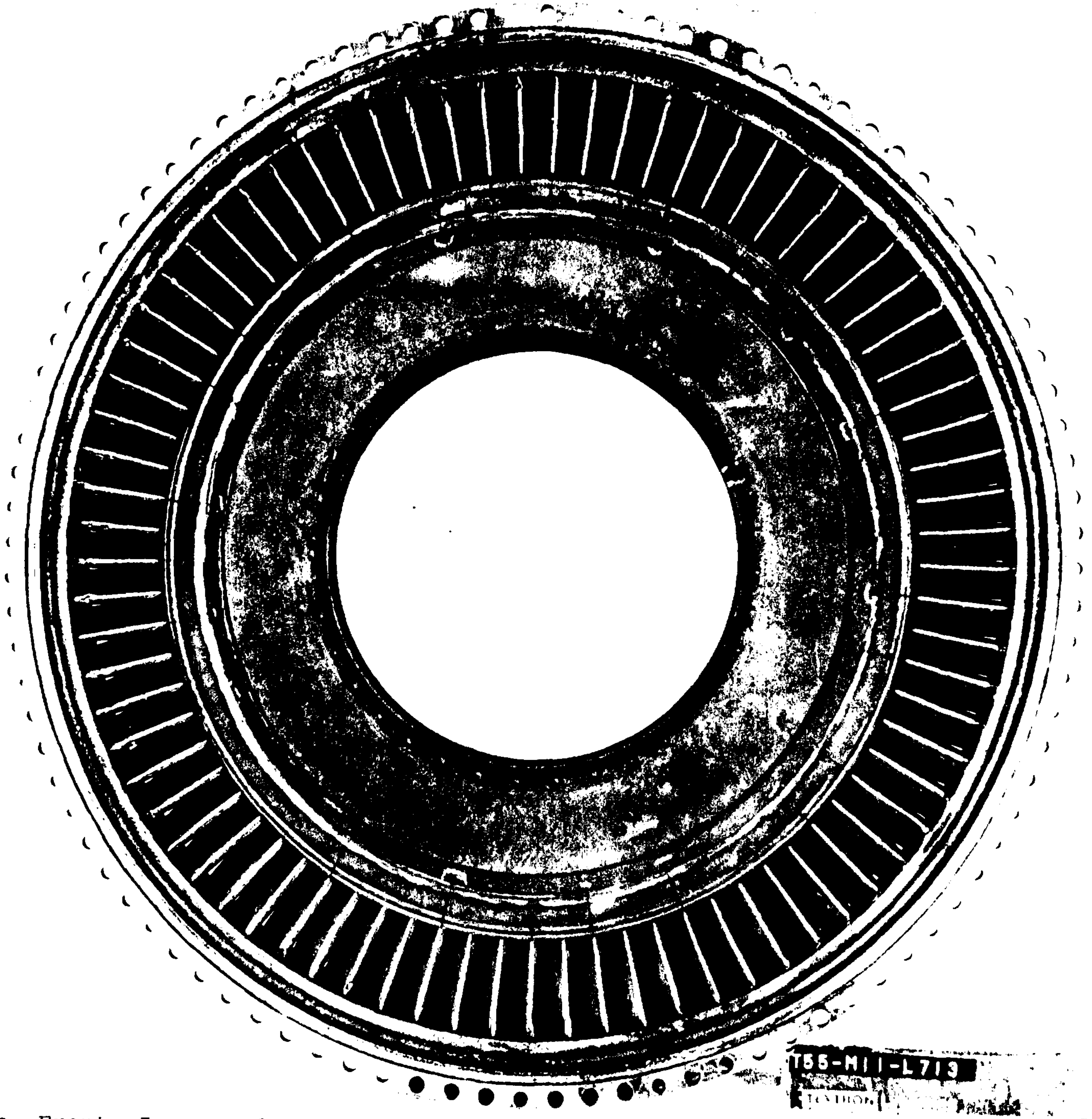


Figure 19A Second Nozzle, Front, Inner and Outer Shroud Cracking, Posttest

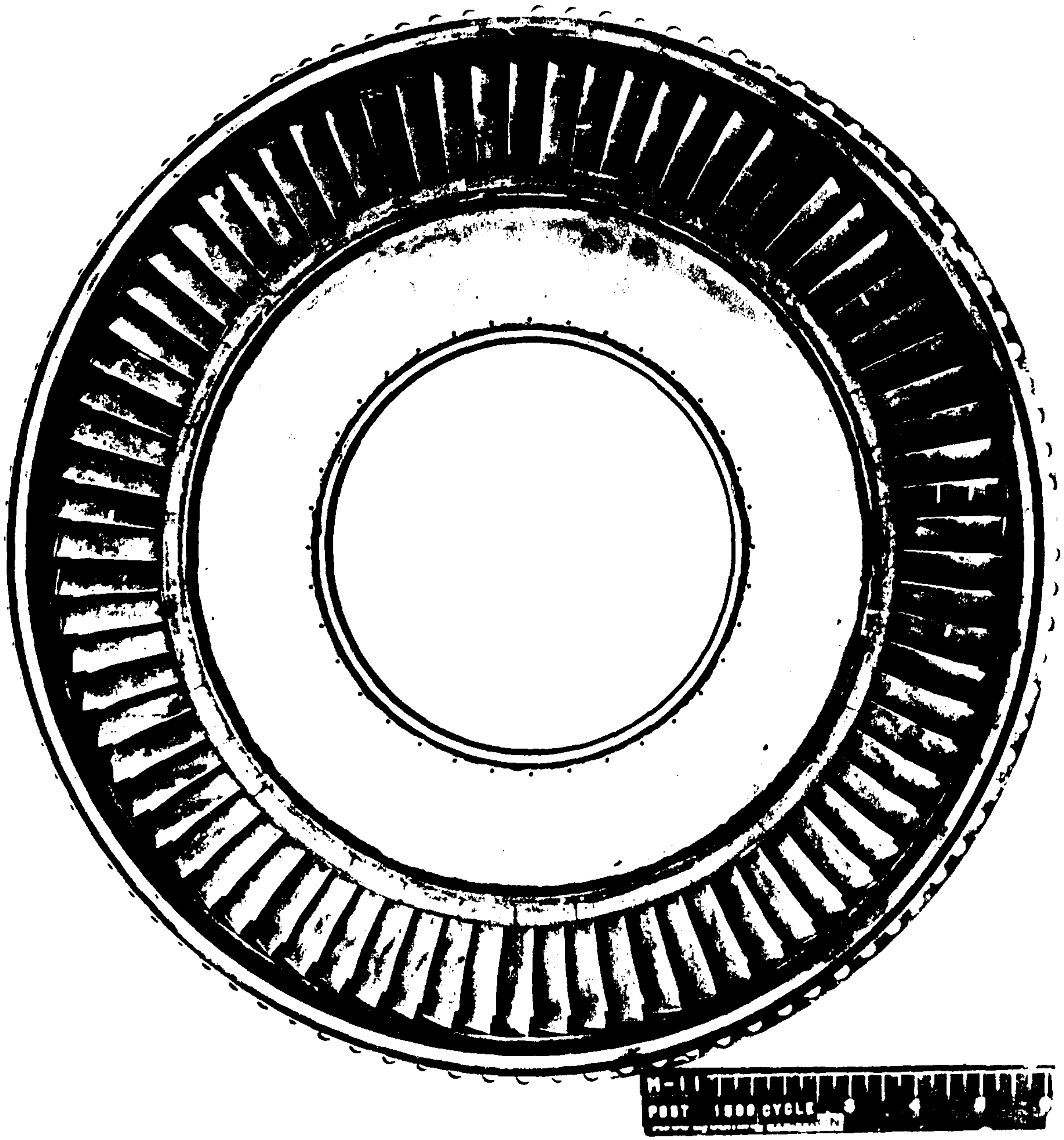


Figure 20 Second Nozzle, Rear, Inner Shroud Cracking,
Post 1500

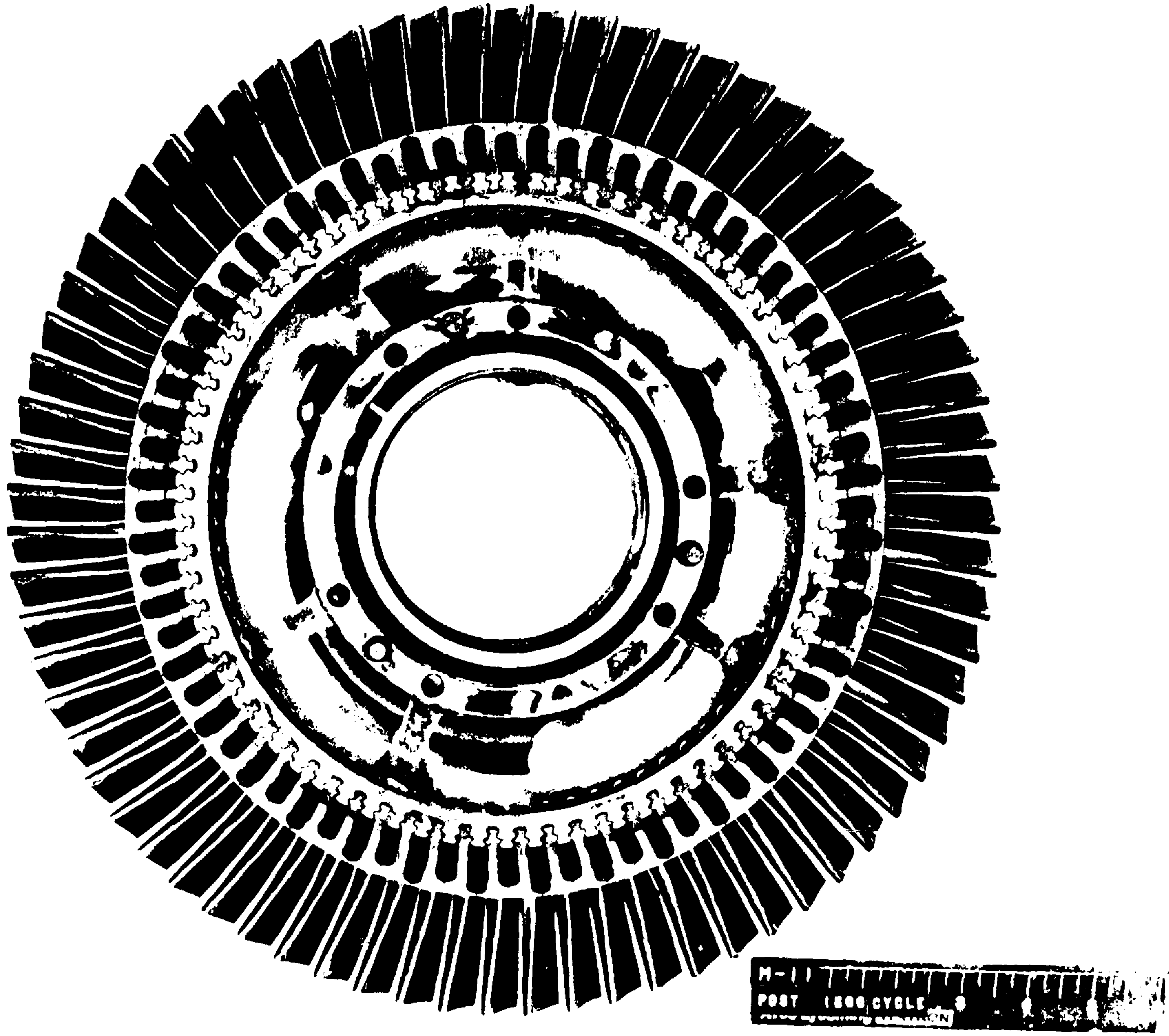


Figure 21 Second Turbine, Front, Post 1500

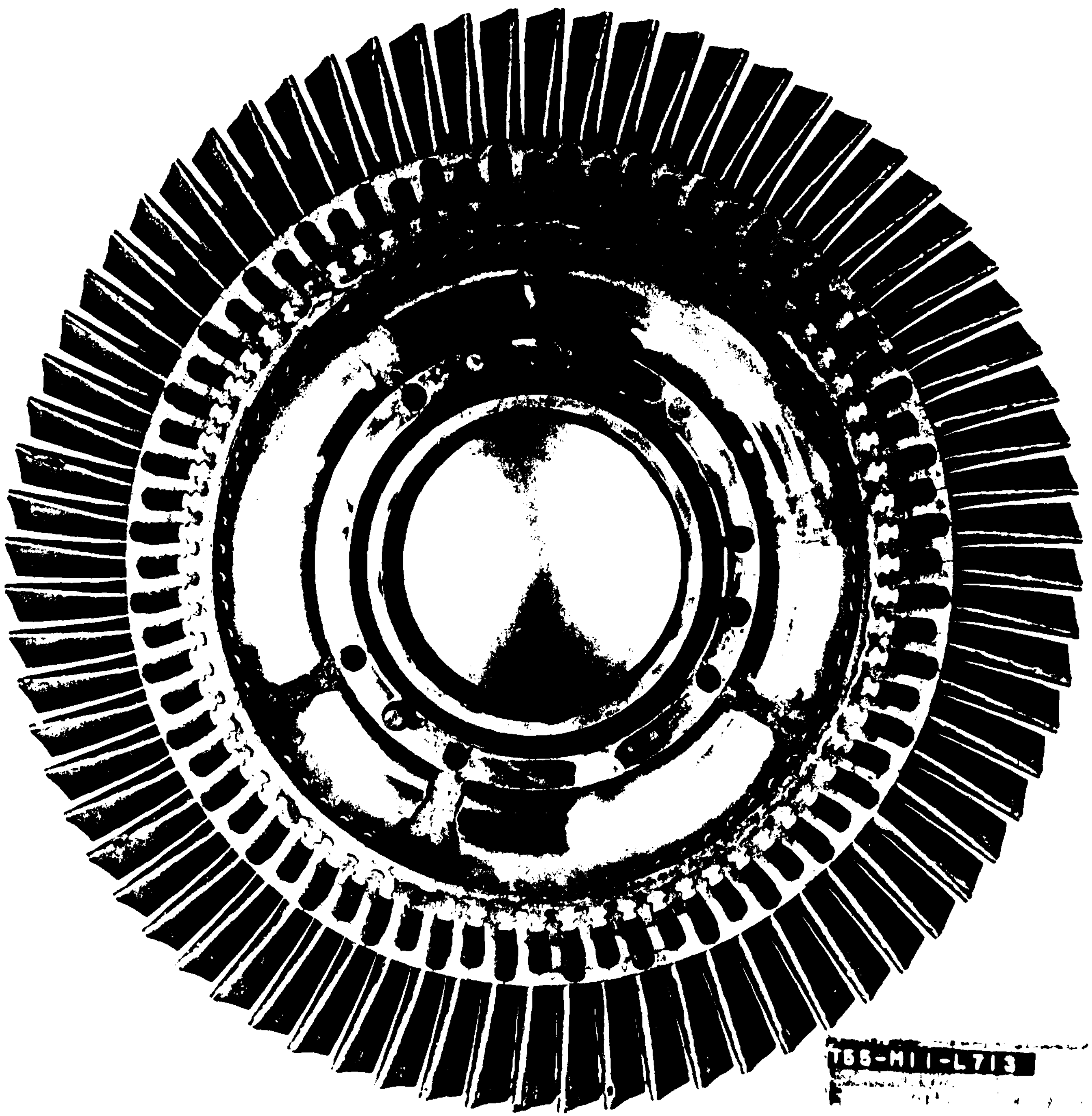


Figure 21A Second Turbine, Front, Posttest

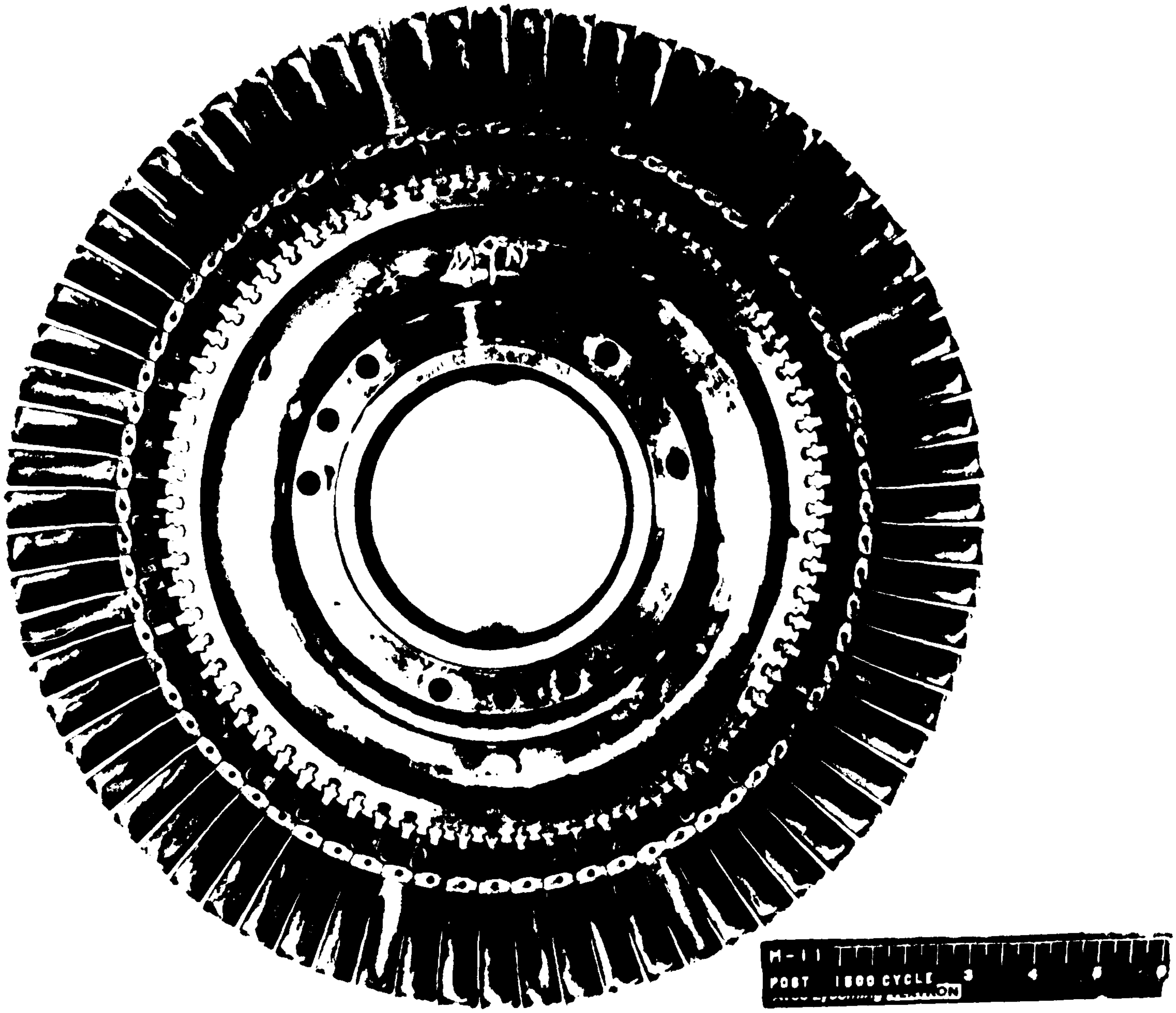


Figure 22 Second Turbine, Rear, Post 1500

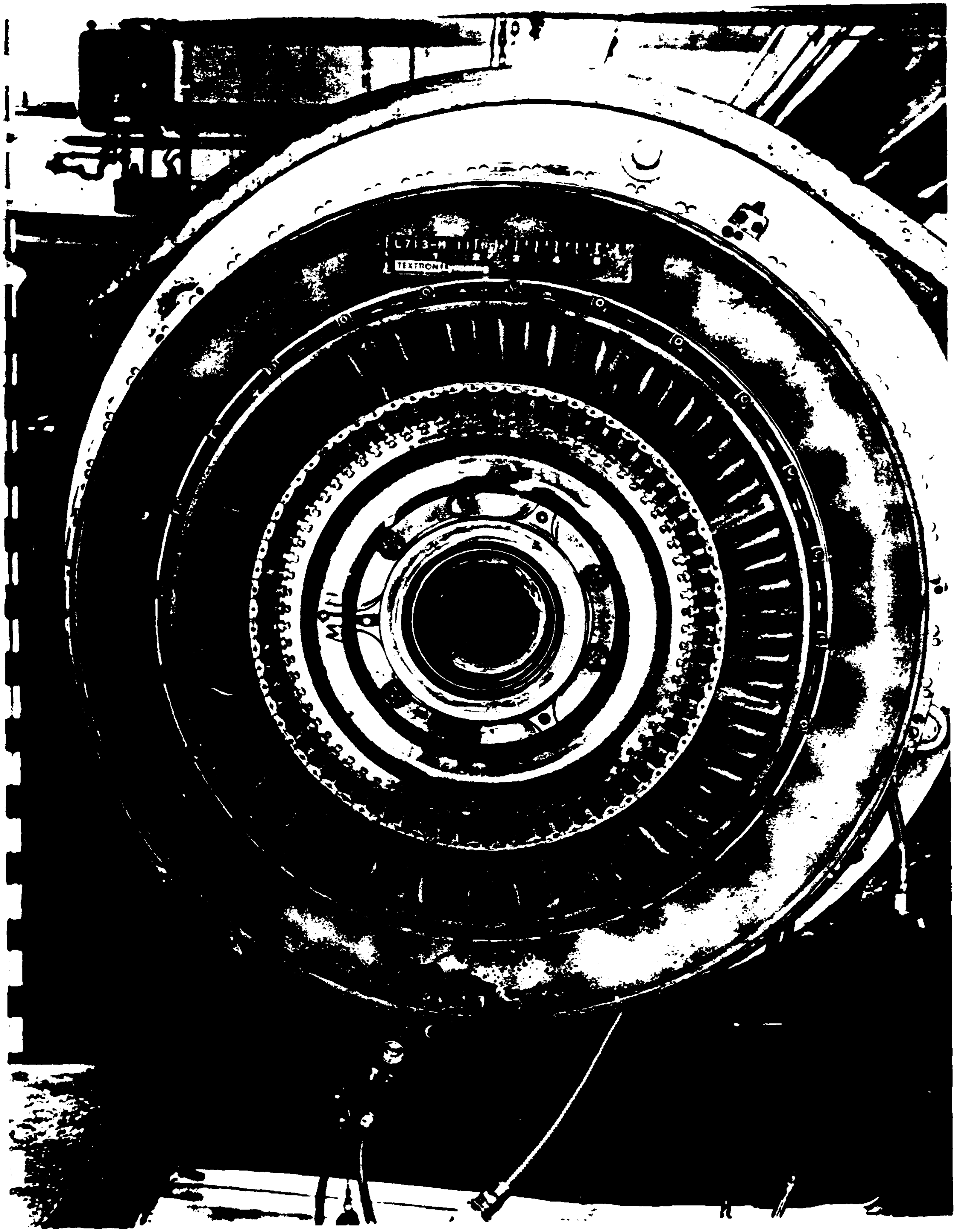


Figure 23 Second Turbine, Rear, Posttest

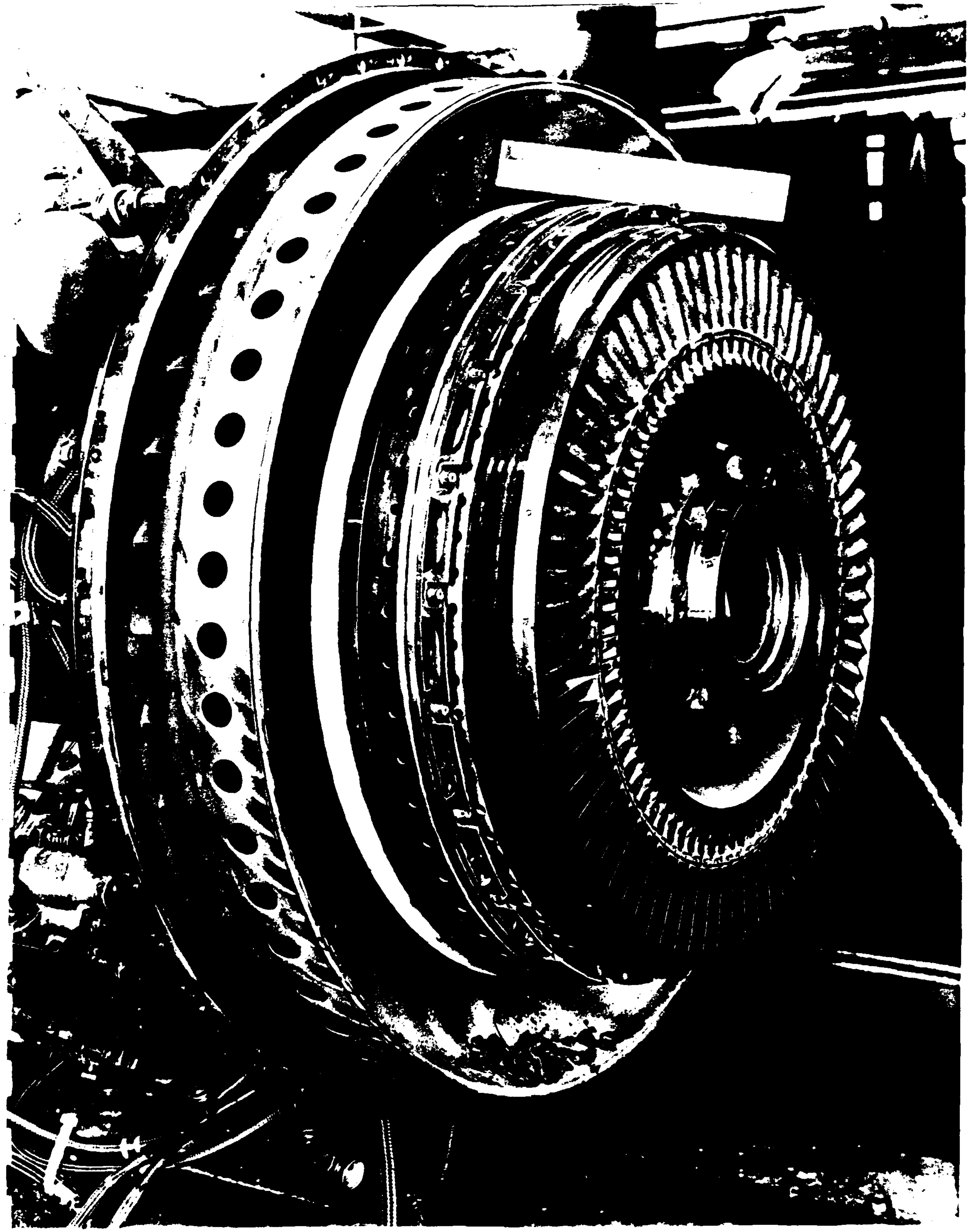


Figure 24 Second Turbine and Combustor Curl, Posttest

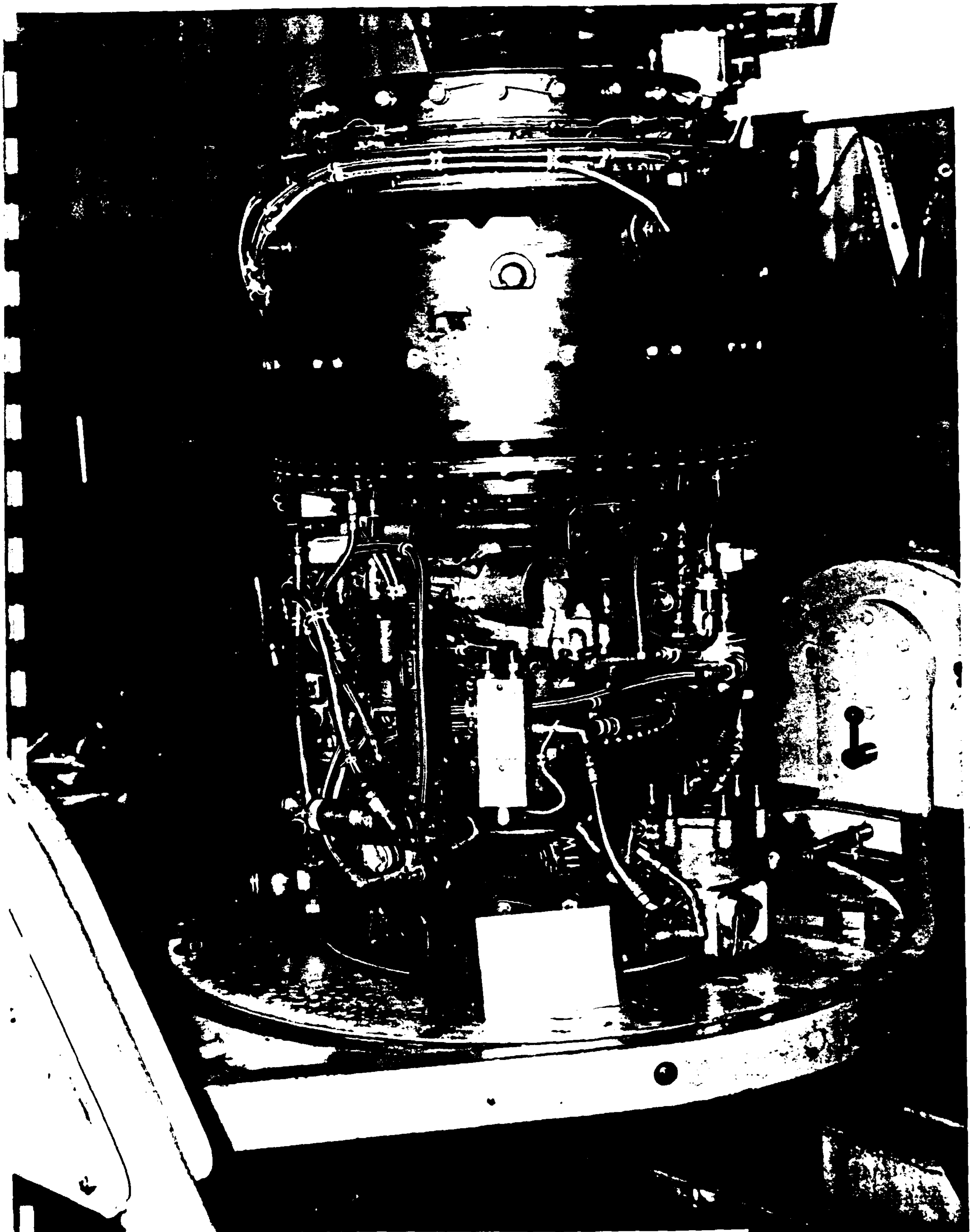


Figure 25 Engine, Overall, Pretest

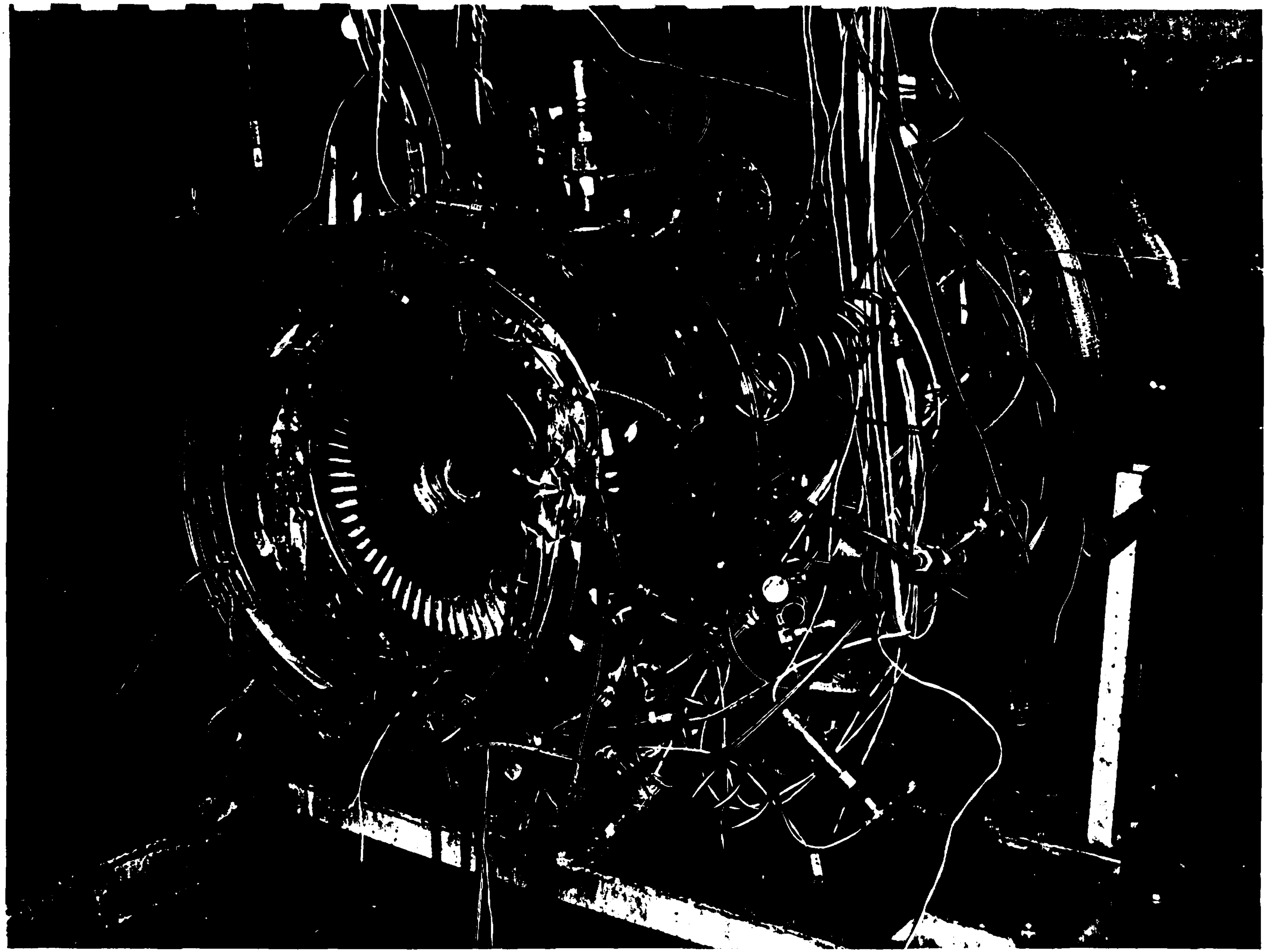


Figure 26 Engine, Overall, Posttest

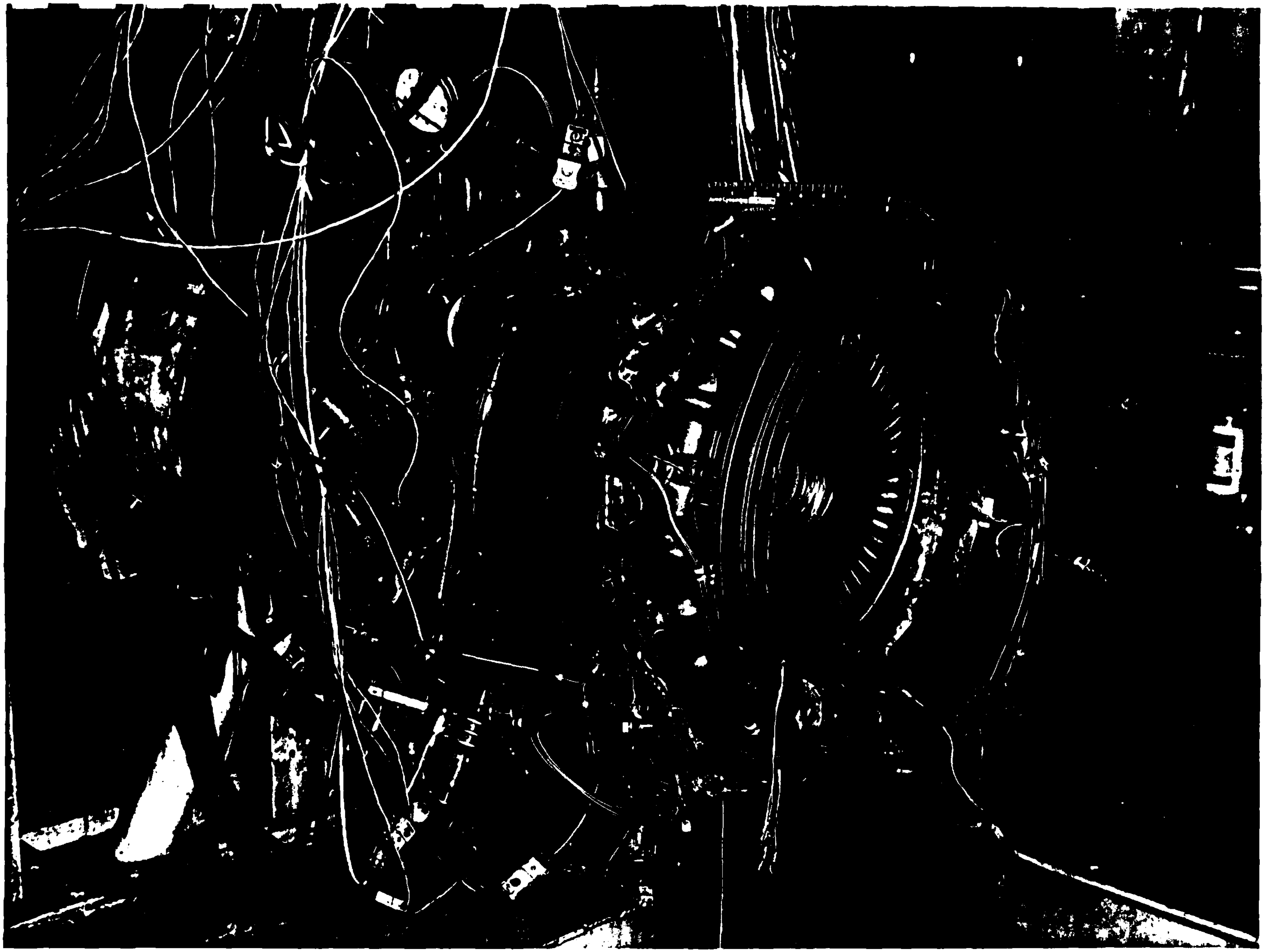


Figure 27 Engine, Overall, Posttest

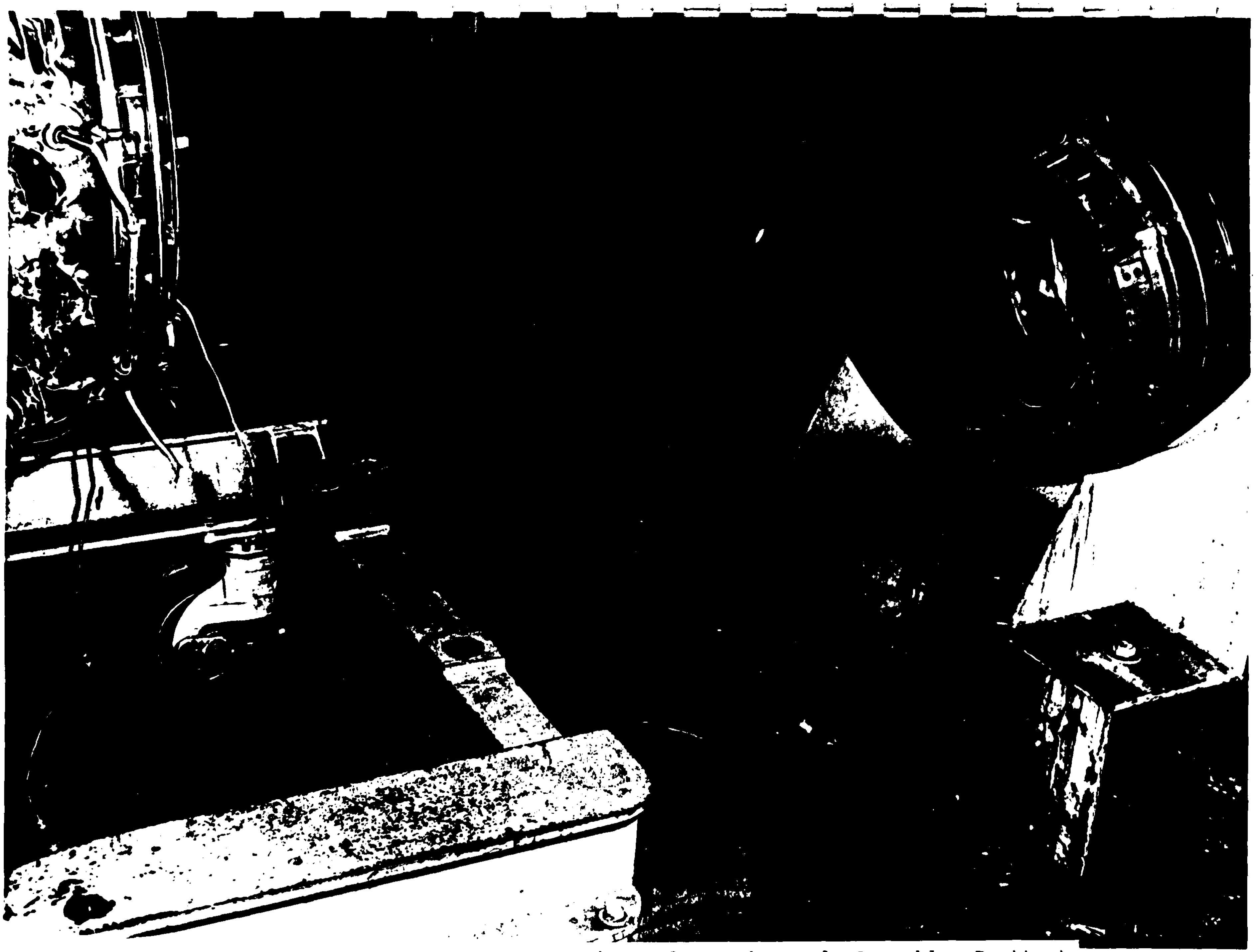


Figure 28 Combustor Housing and Fourth Nozzle Assembly, Posttest

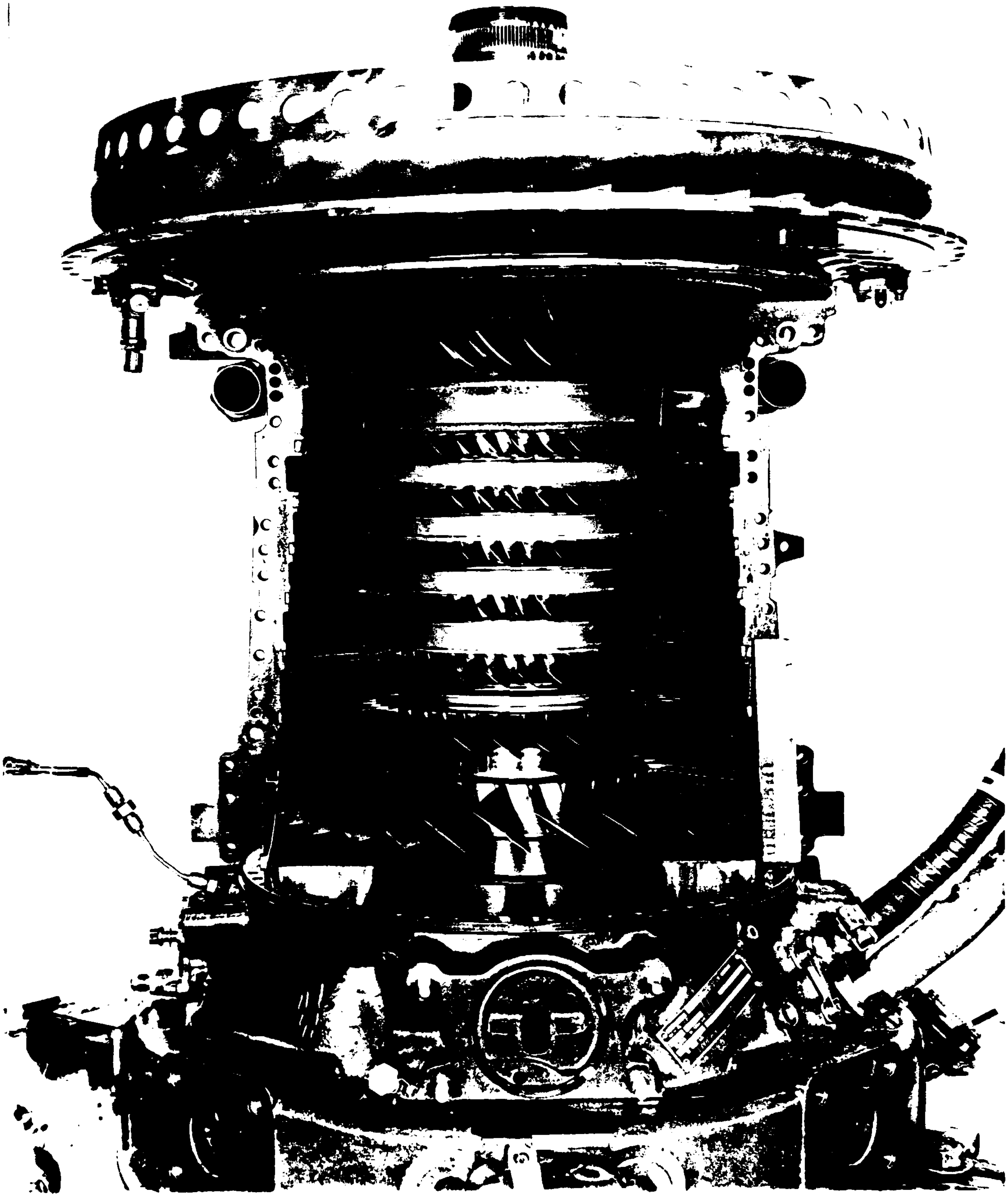


Figure 29 Compressor, Overall, Posttest

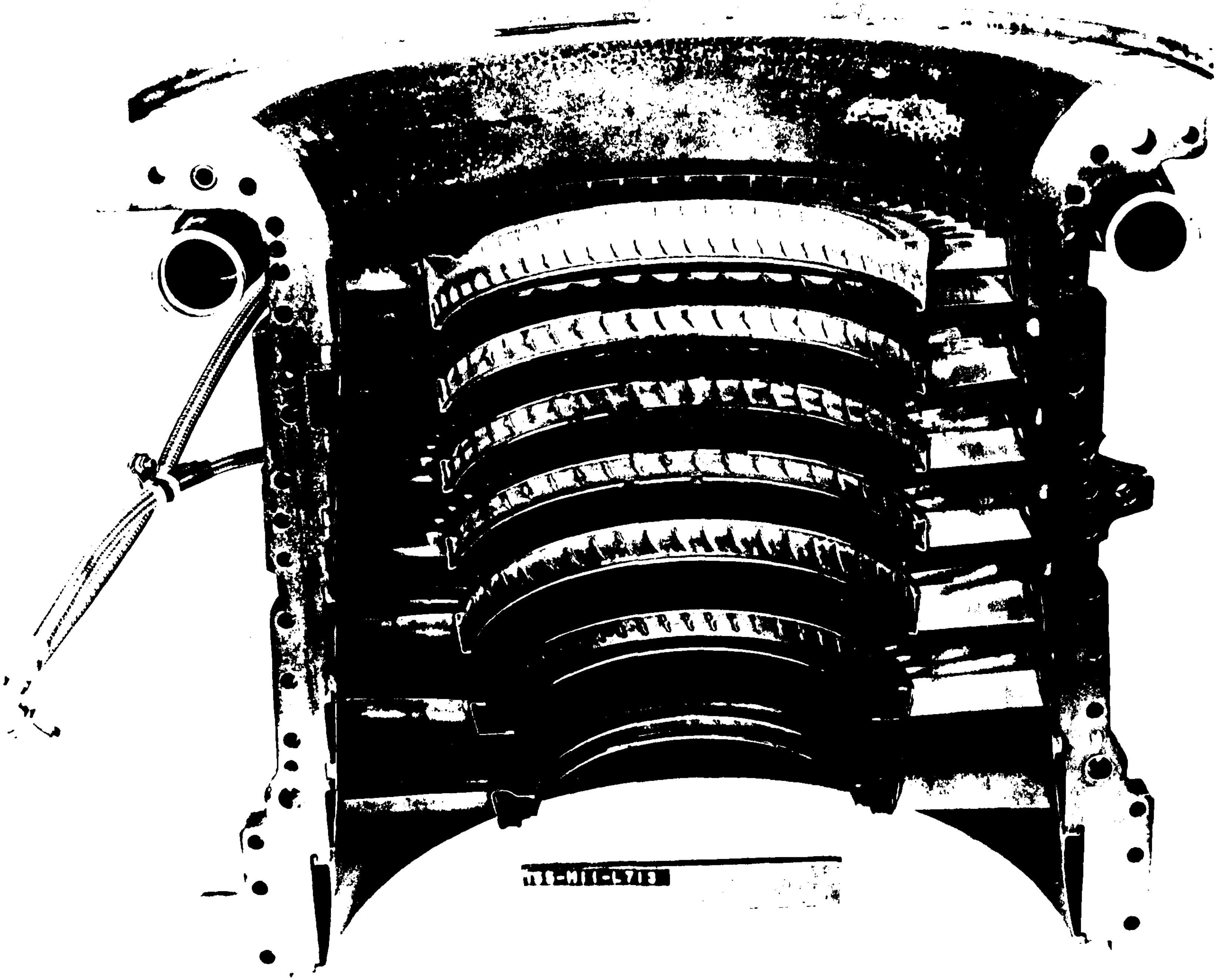


Figure 30 Compressor Housing and Stators, Posttest

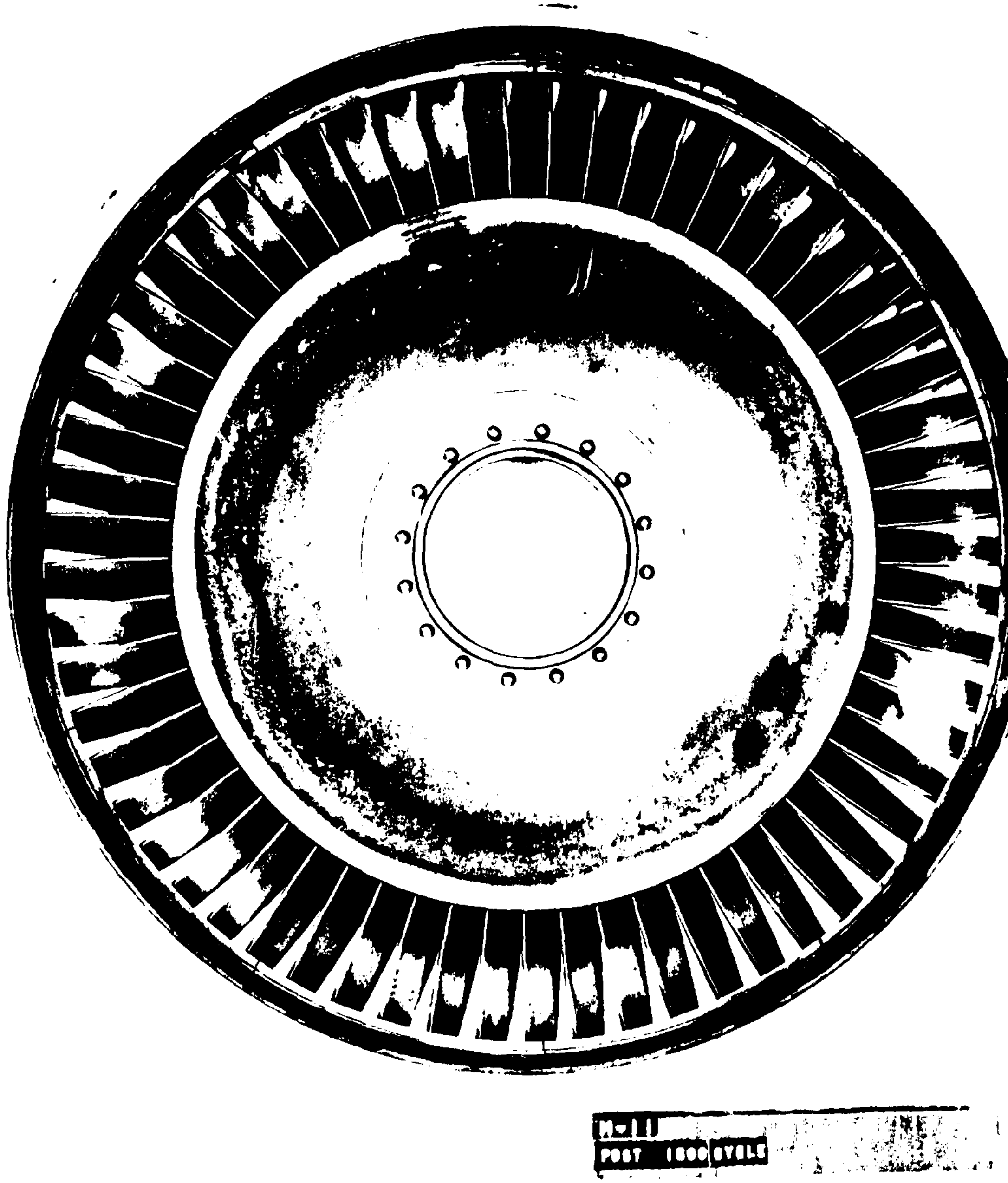


Figure 31 Third Nozzle, Front, Post 1500

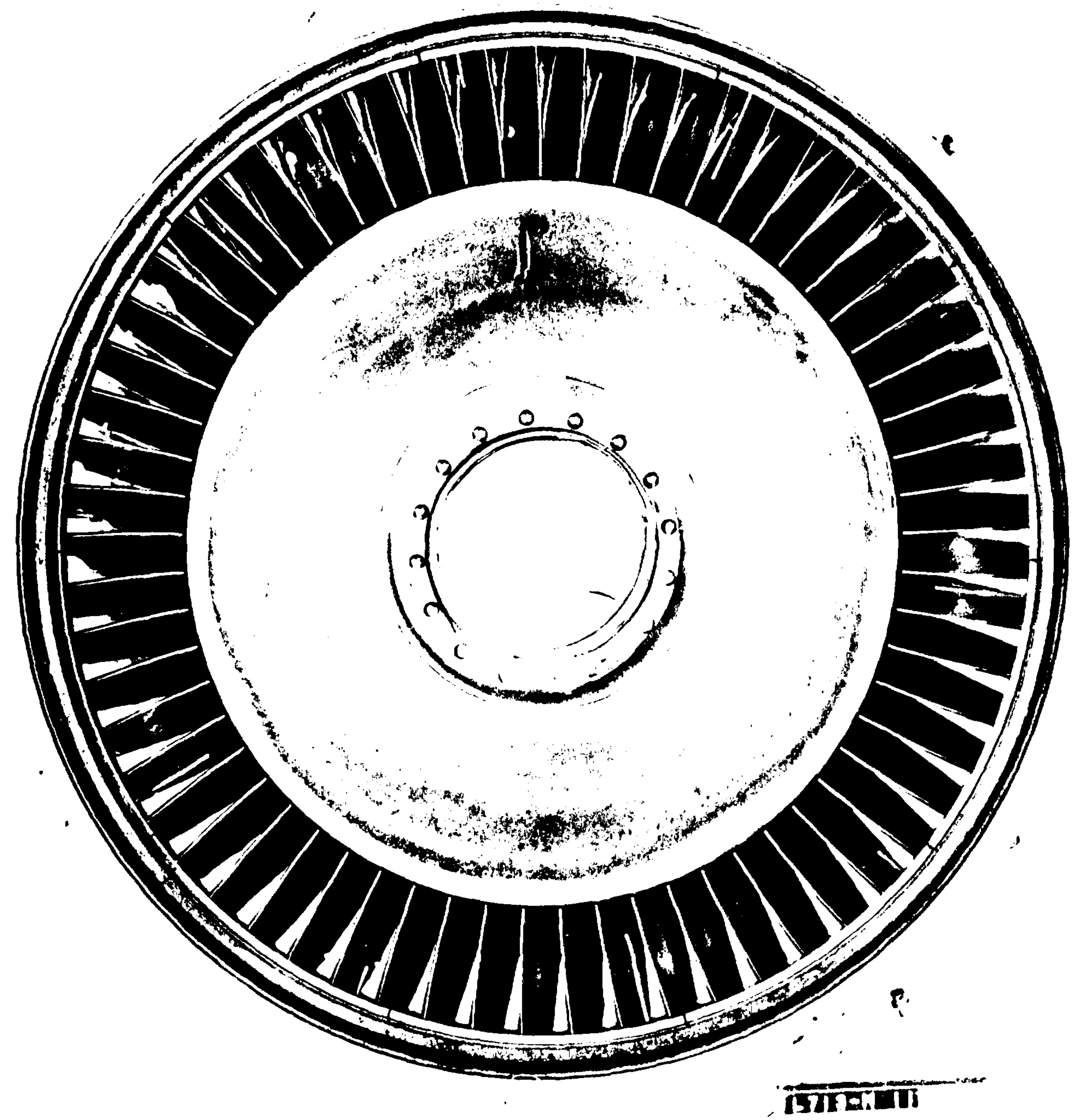


Figure 32 Third Nozzle, Front, Posttest

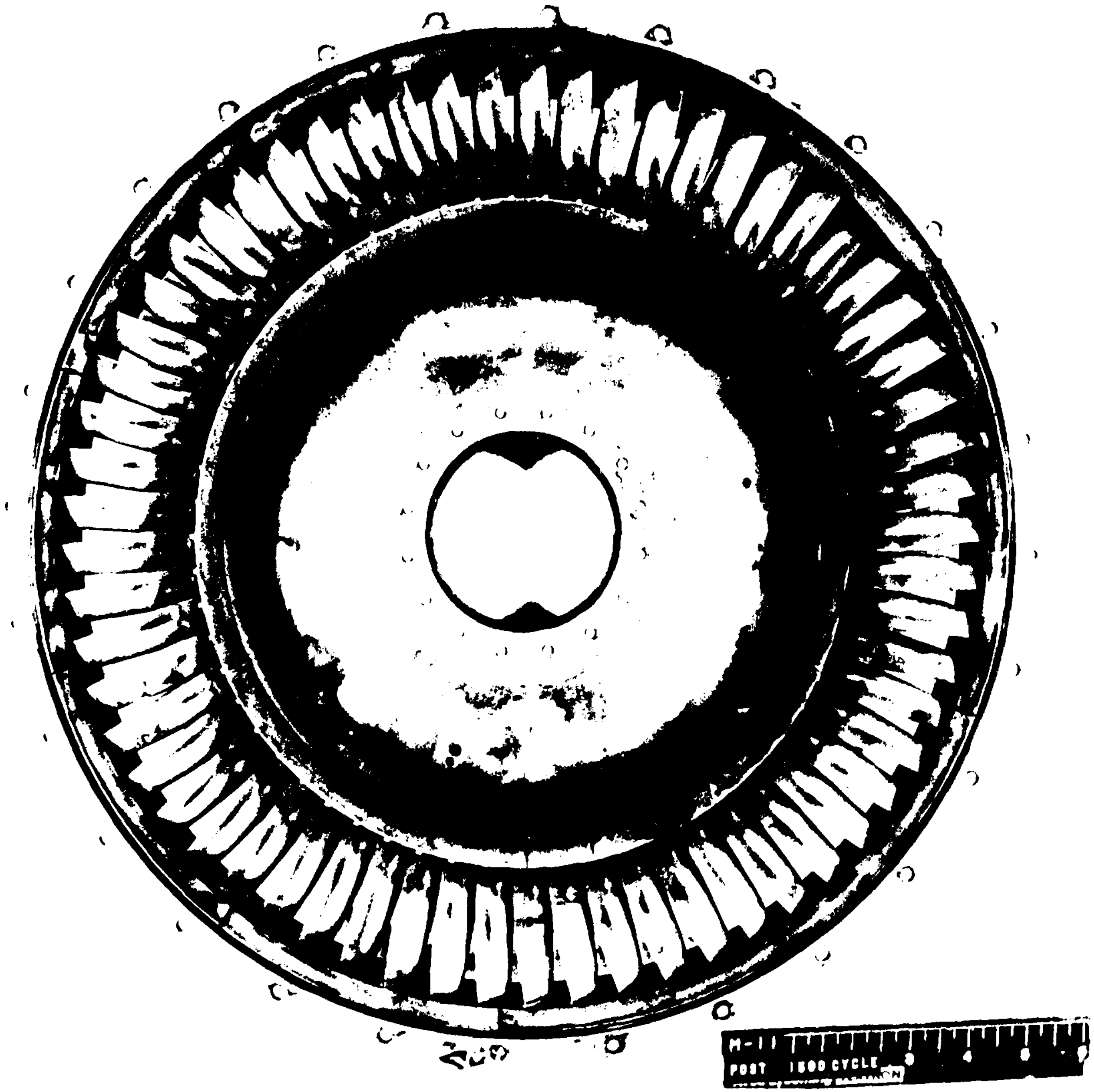


Figure 33 Third Nozzle, Rear, Inner Shroud Cracks, Post 1500

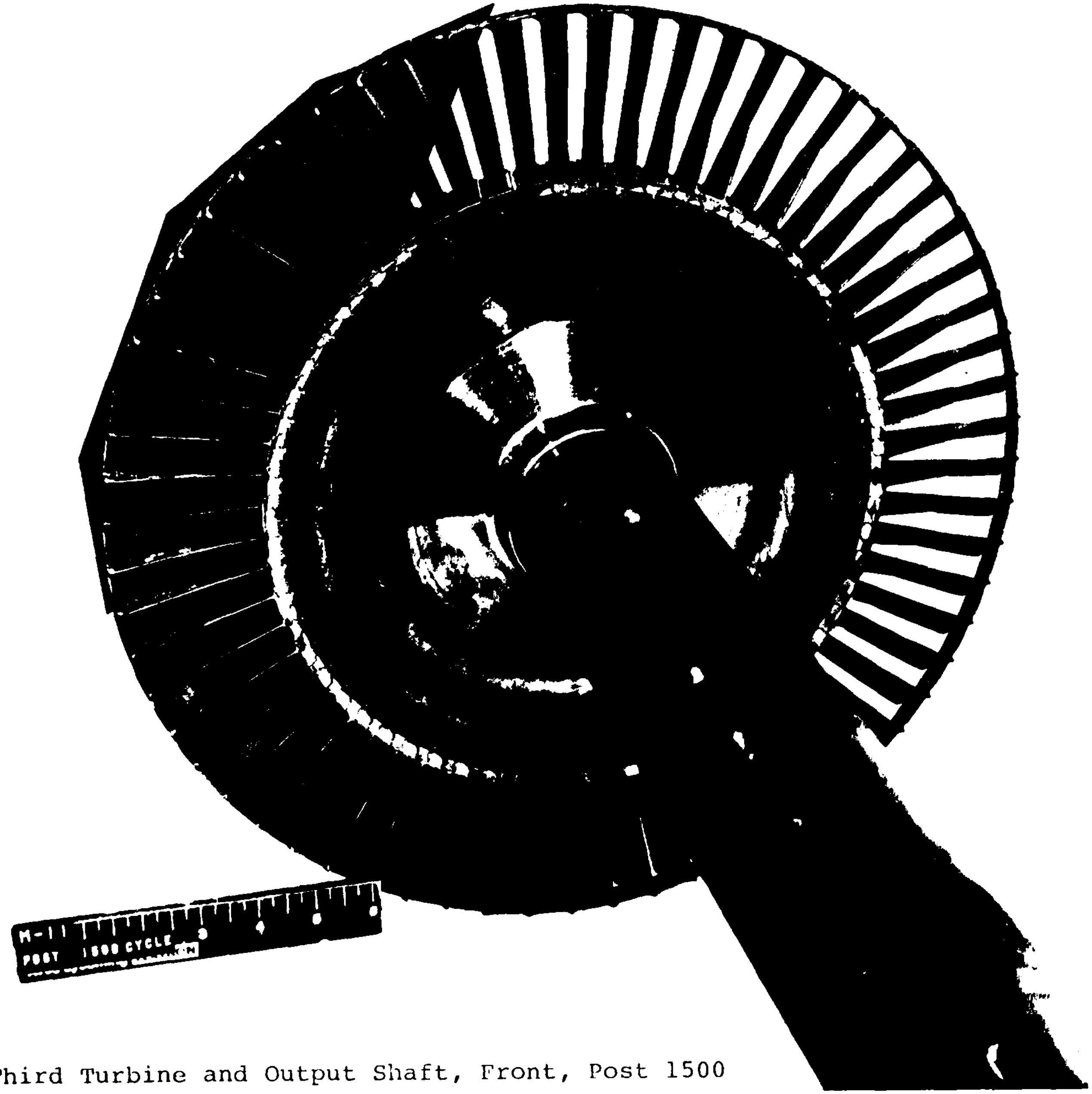


Figure 34 Third Turbine and Output Shaft, Front, Post 1500

Figure 35 Third Turbine, Closeup of Blade Roots and Rivets, Post 1500

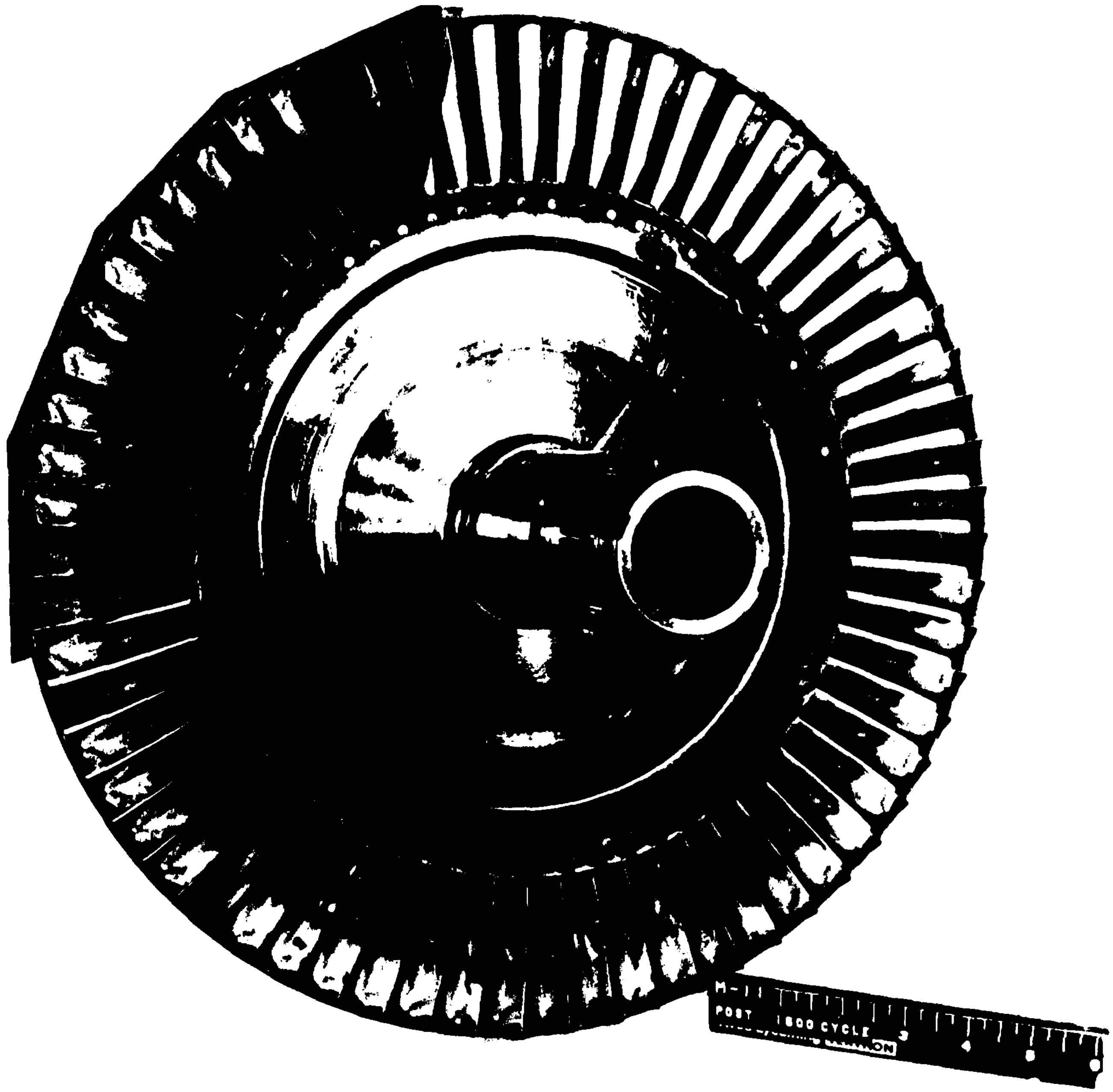


Figure 36 Third Turbine and Output Shaft, Rear, Post 1500

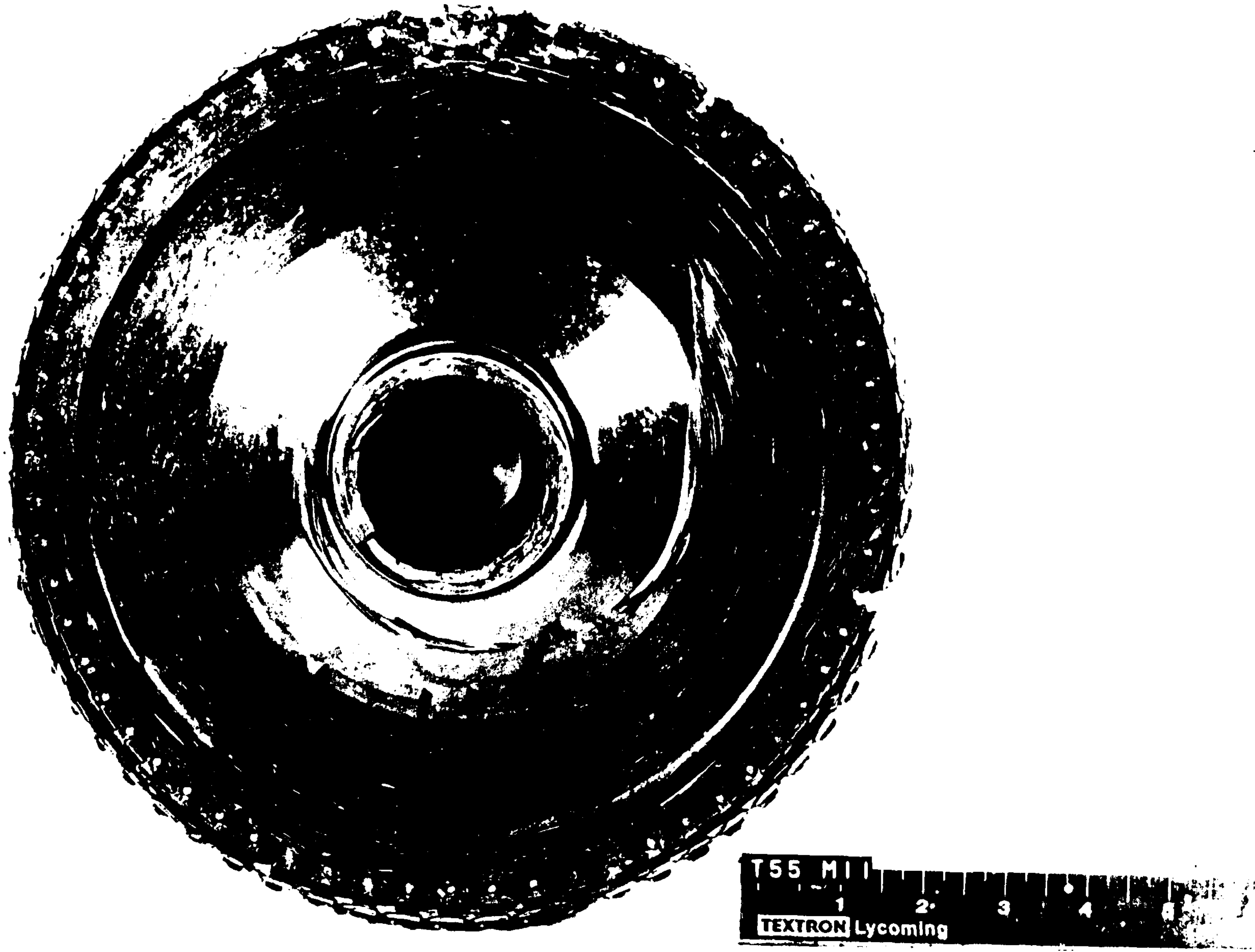


Figure 37 Third Turbine and Shaft Fracture Surface, Front

Figure 38 Third Turbine and Shaft Fracture Surface, Rear

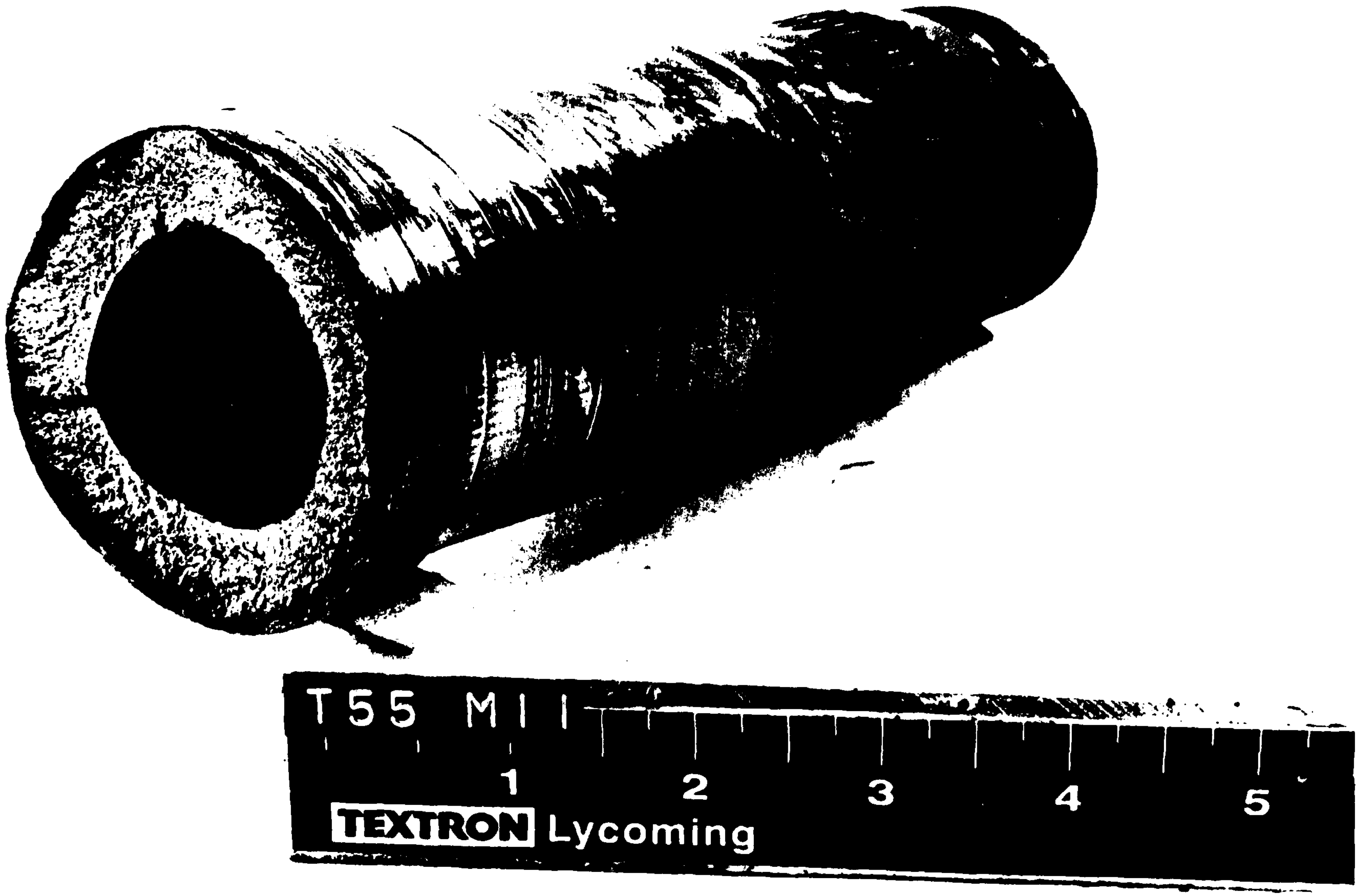


Figure 39 Output Shaft, Rear Section, Fracture Surface and Scoring

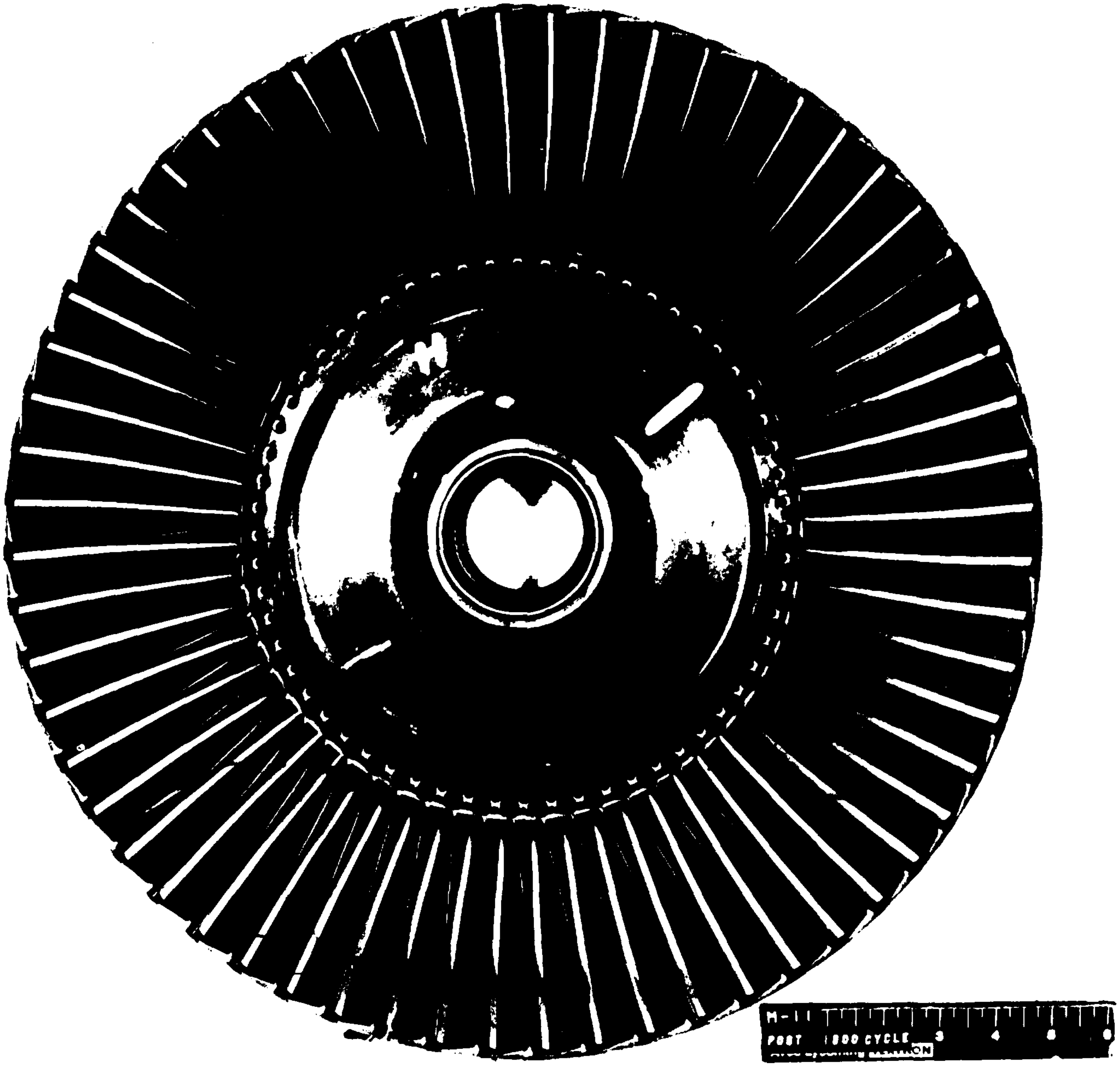


Figure 40 Fourth Turbine, Front, Post 1500

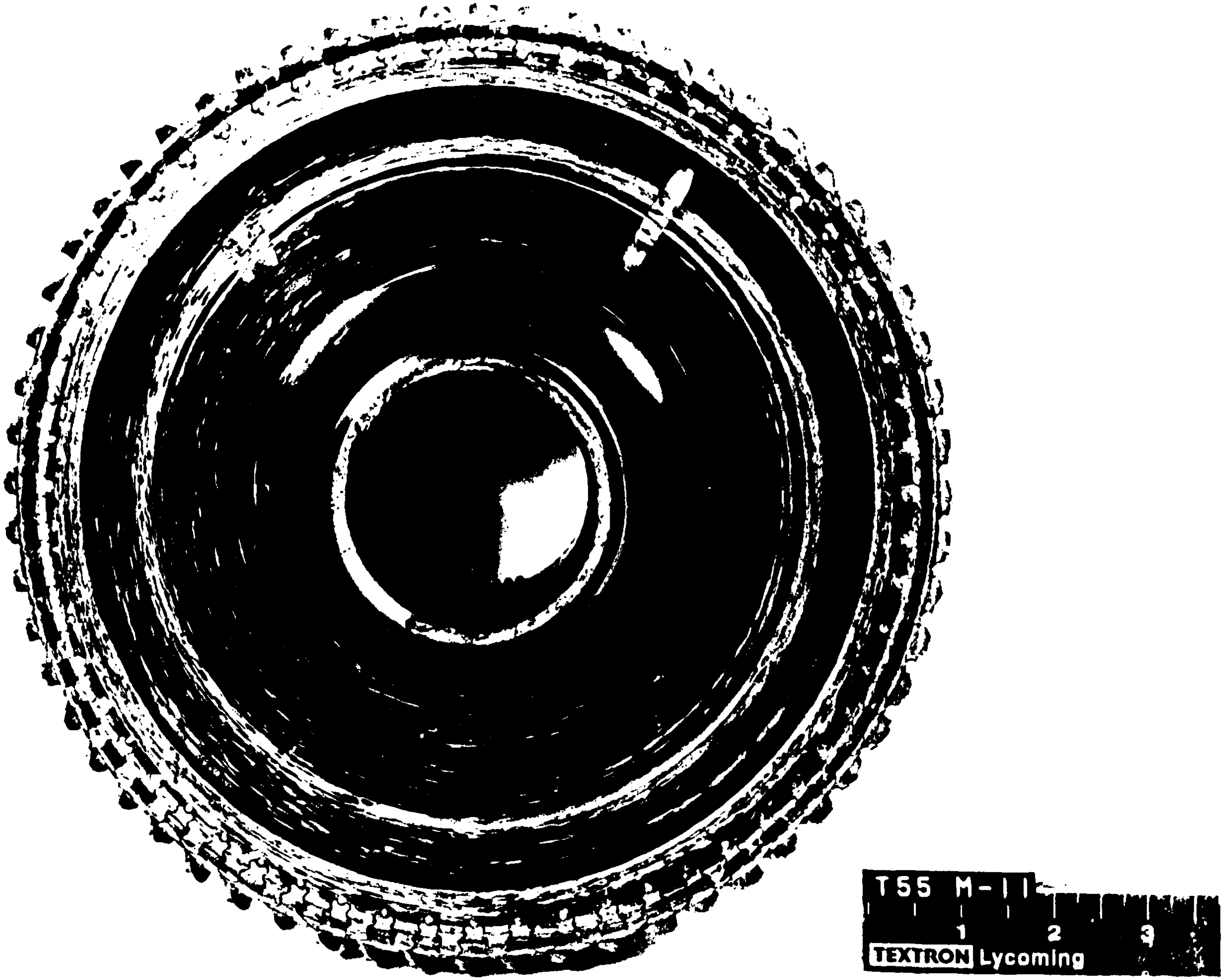


Figure 41 Fourth Turbine, Front, Posttest

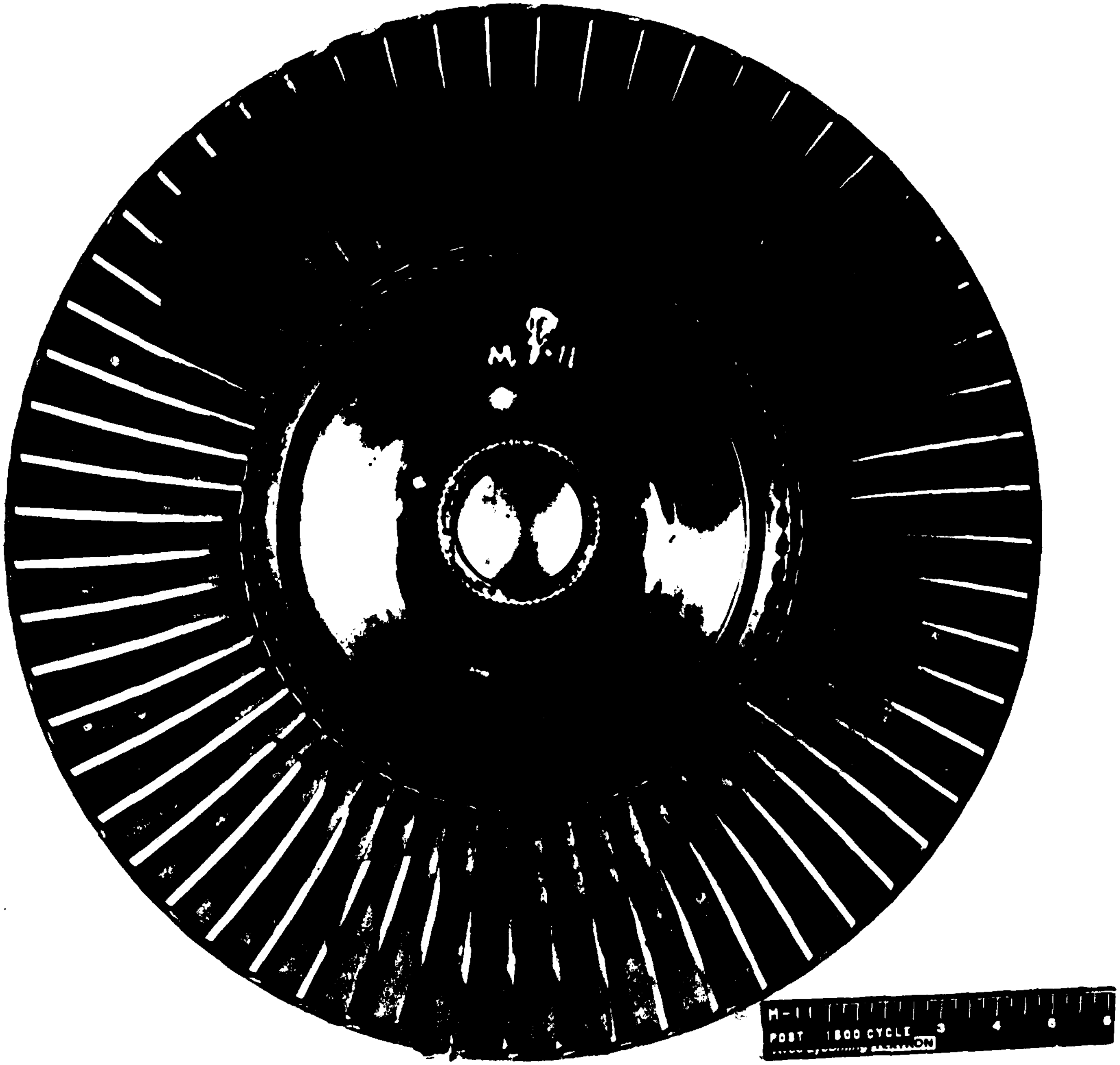


Figure 42 Fourth Turbine, Rear, Post 1500

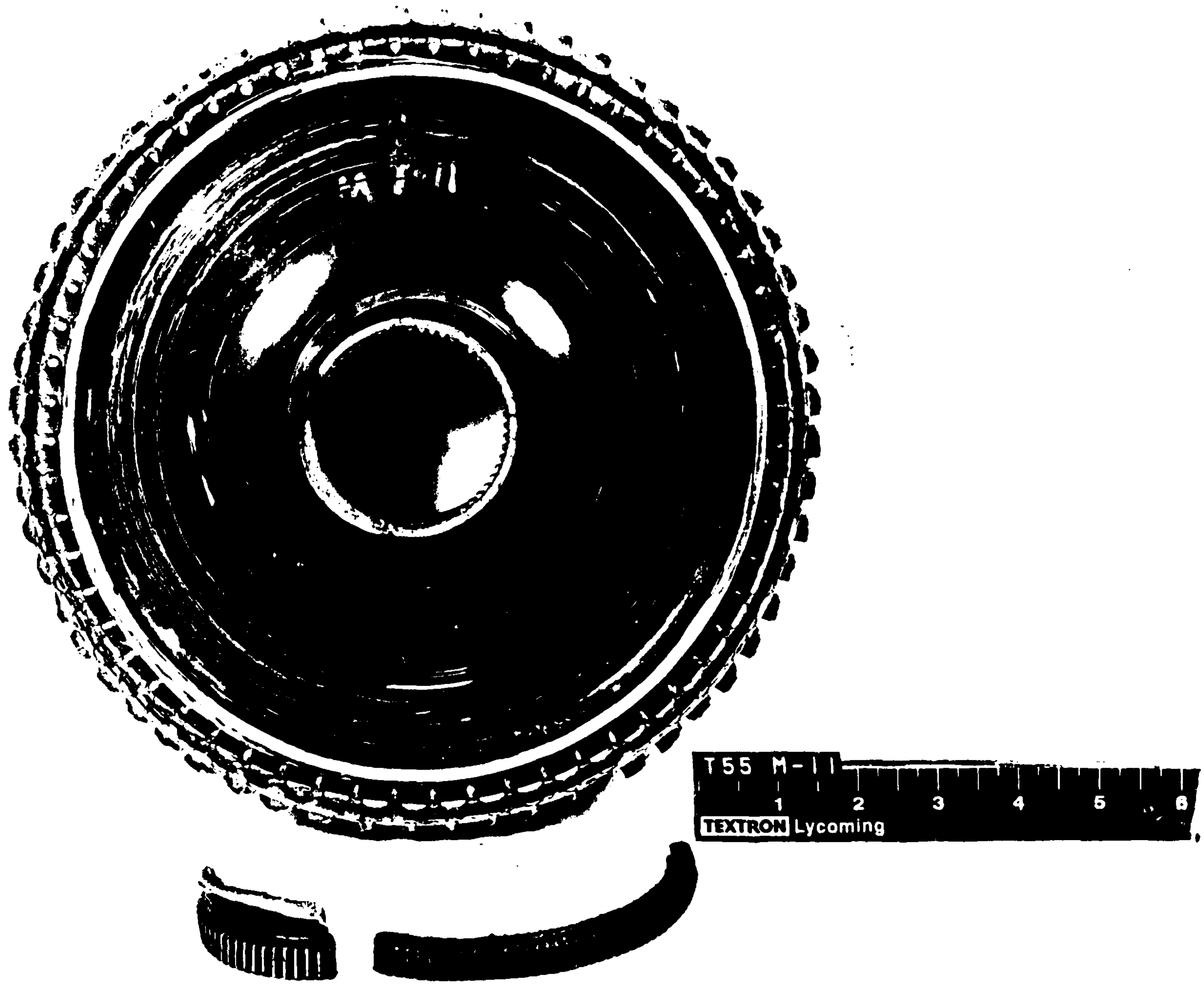


Figure 43 Fourth Turbine, Rear, Posttest

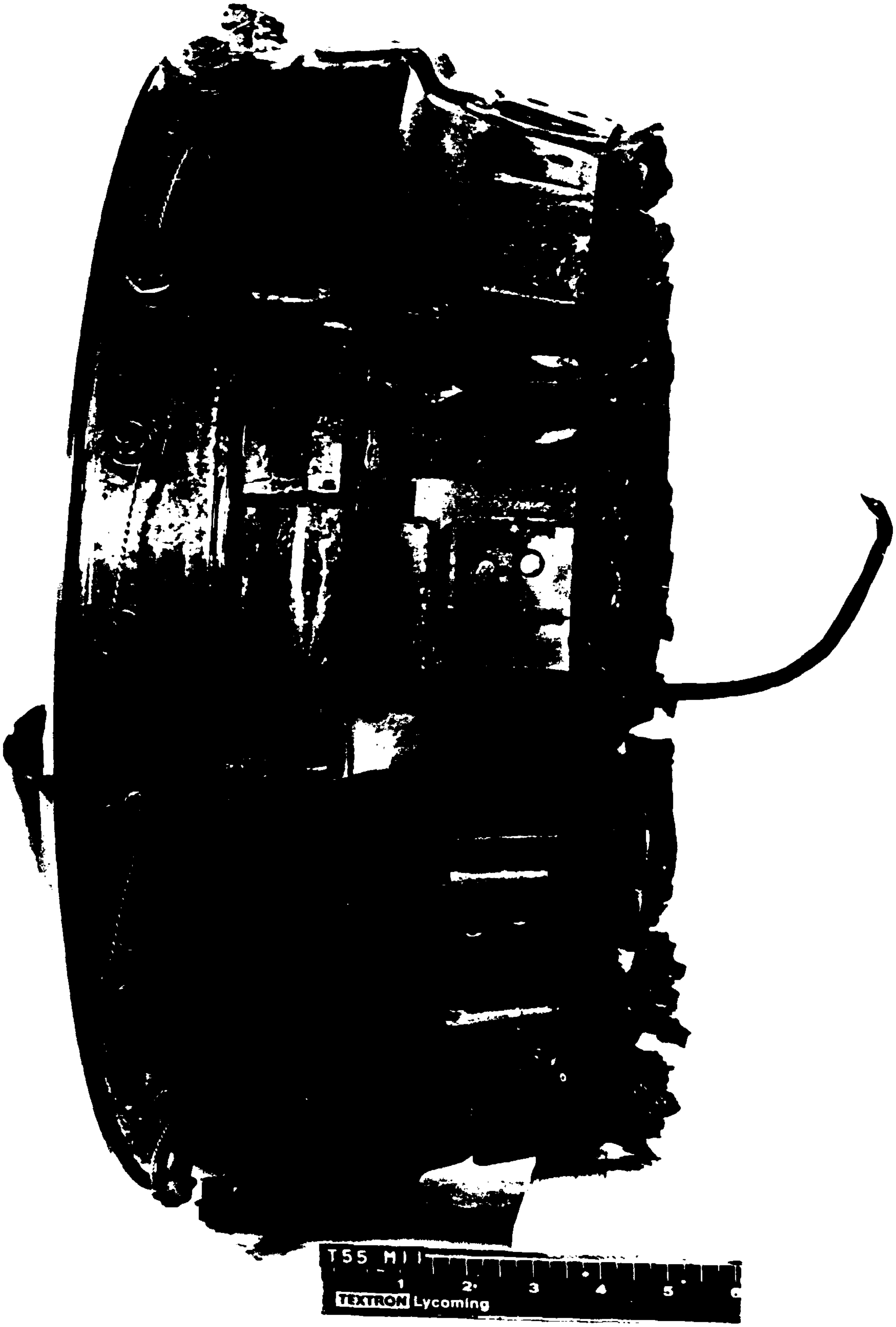


Figure 44 Fourth Nozzle Assembly

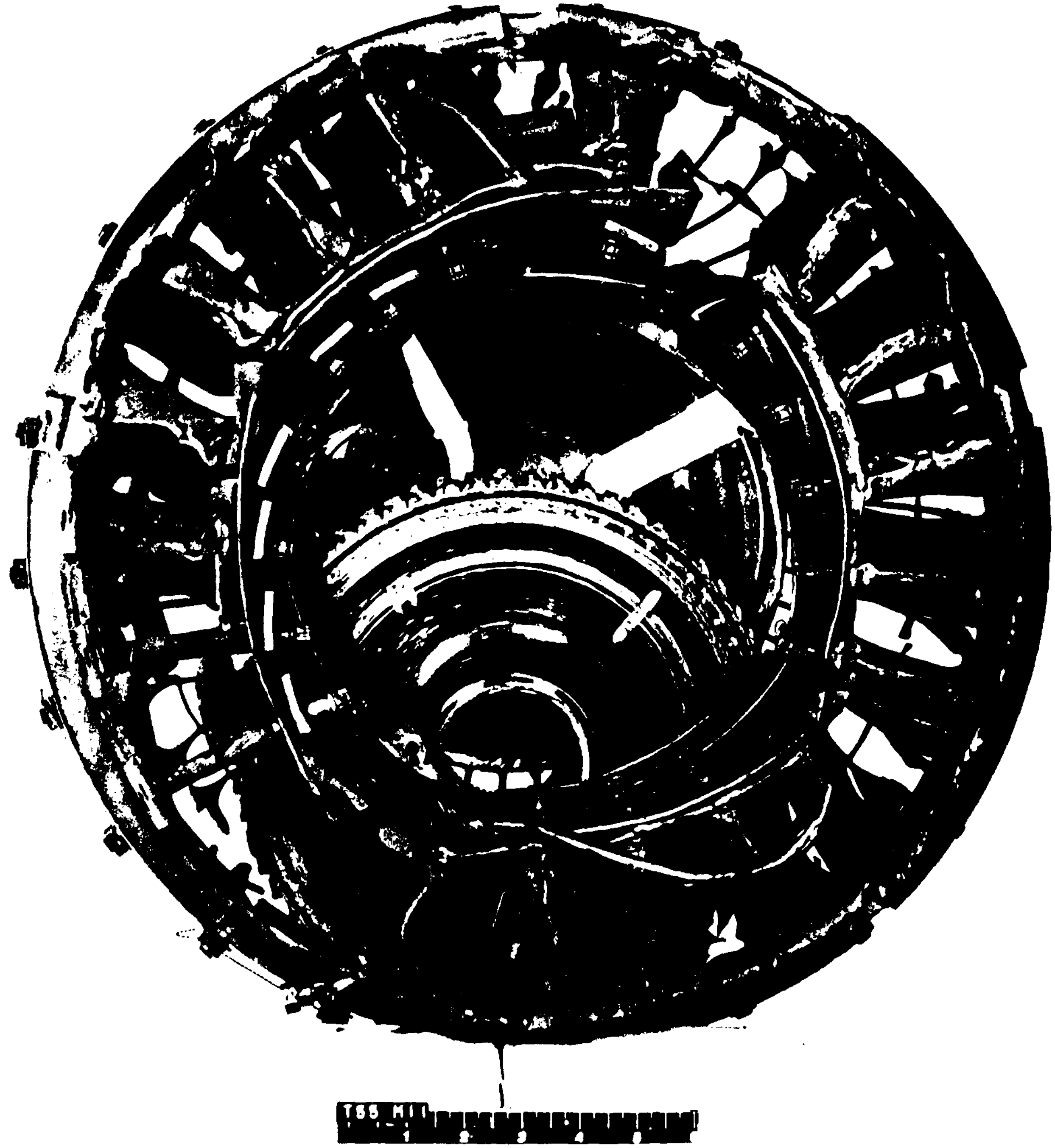


Figure 45 Fourth Nozzle Assembly with Fourth Turbine and Exit Stator Ring, Front

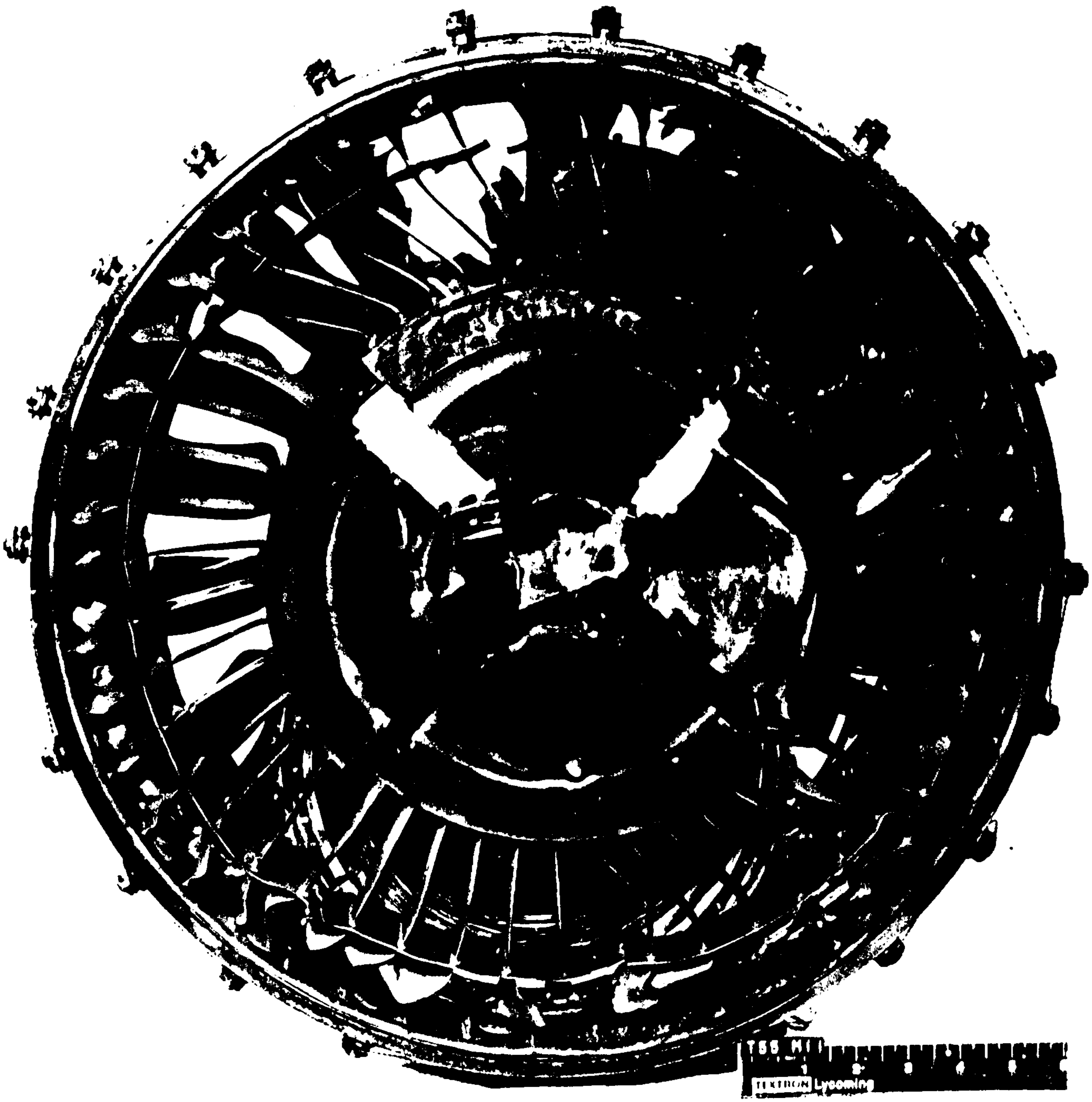


Figure 46 Fourth Nozzle Assembly with Fourth Turbine and Exit Stator Ring, Rear

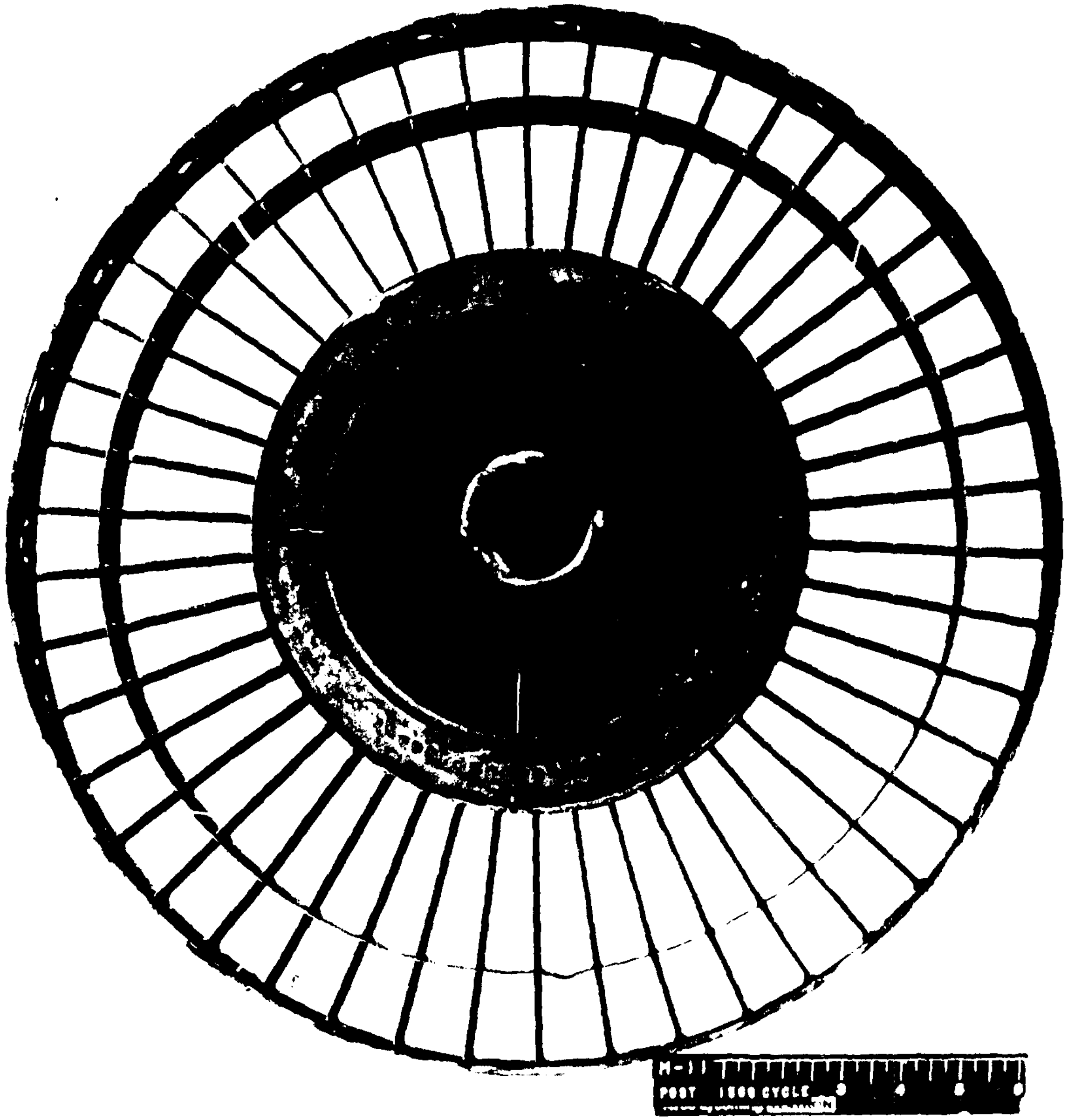


Figure 47 Exit Stator Ring, Rear, Post 1500

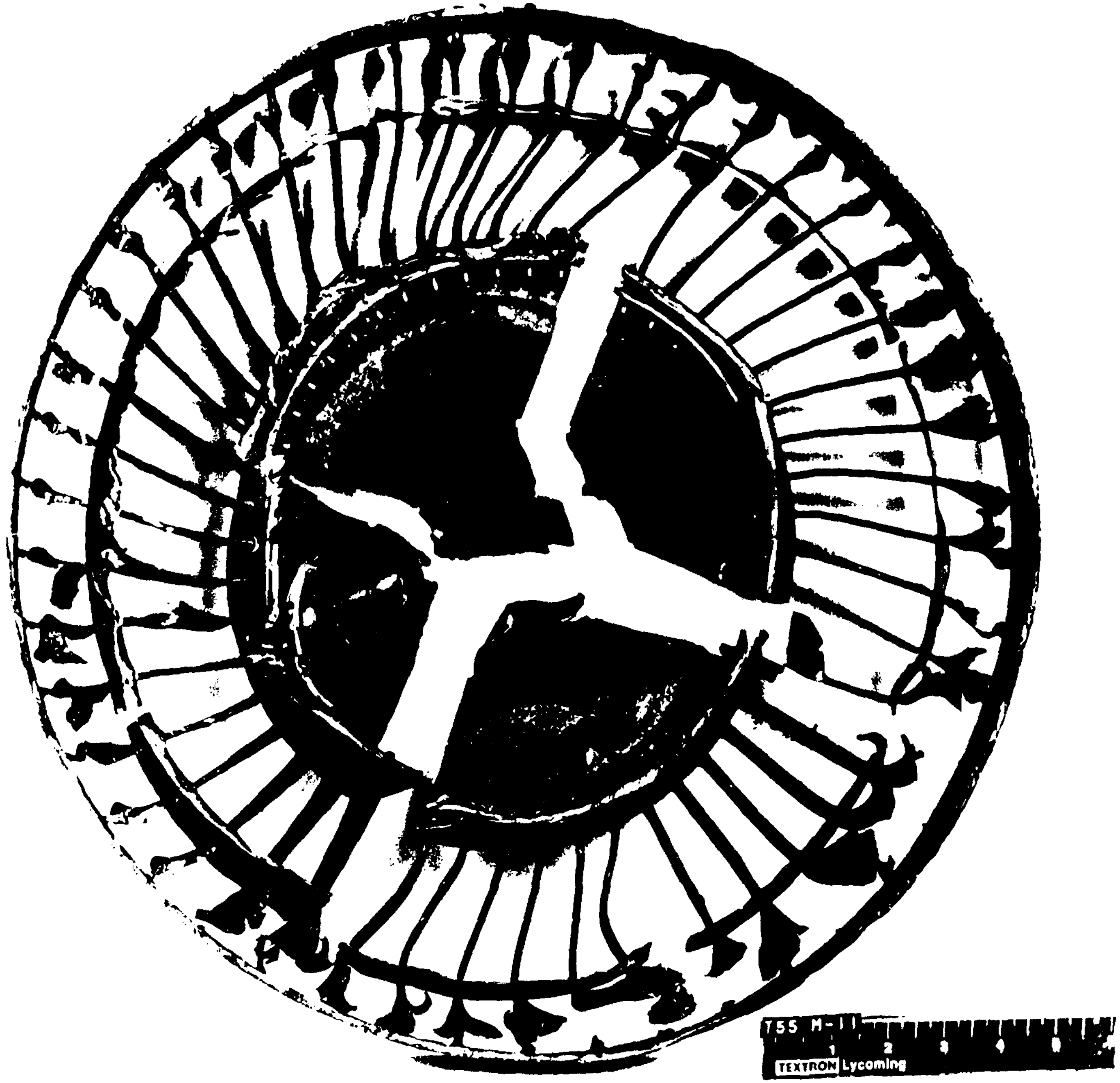


Figure 48 Exit Stator Ring, Front

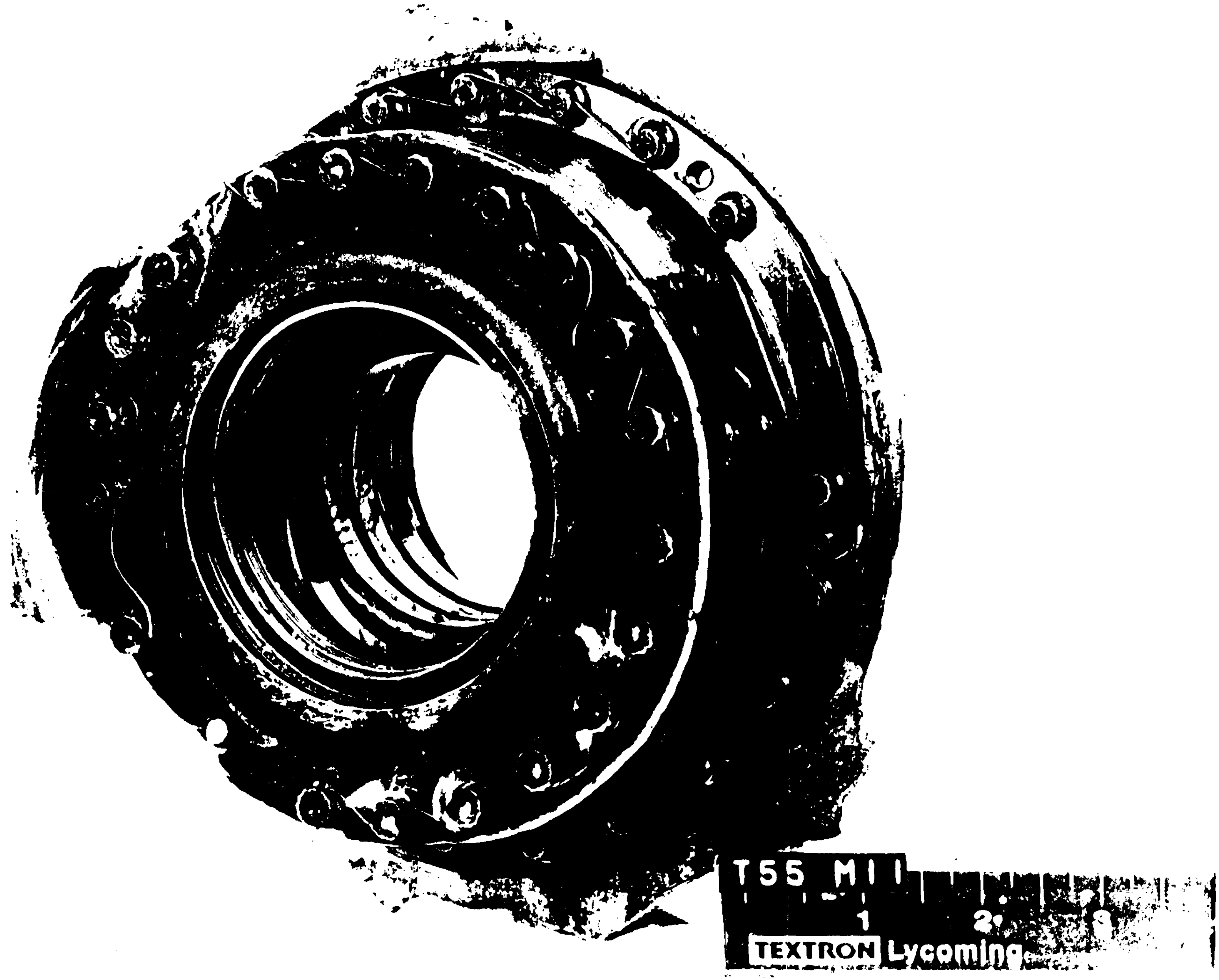


Figure 49 Number 4 and 5 Bearing Package, Front

Figure 50 Number 4 and 5 Bearing Package, Rear

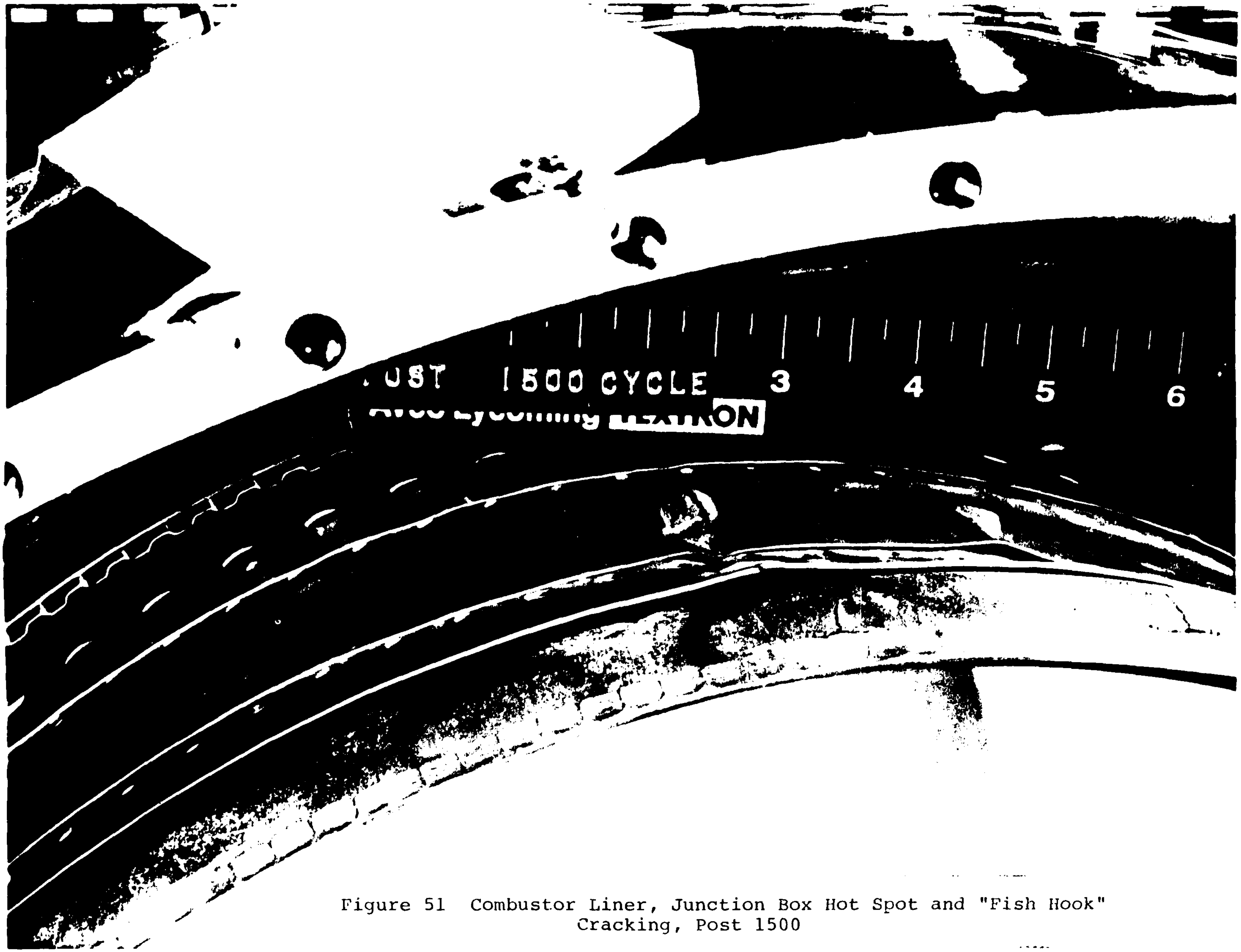


Figure 51 Combustor Liner, Junction Box Hot Spot and "Fish Hook" Cracking, Post 1500

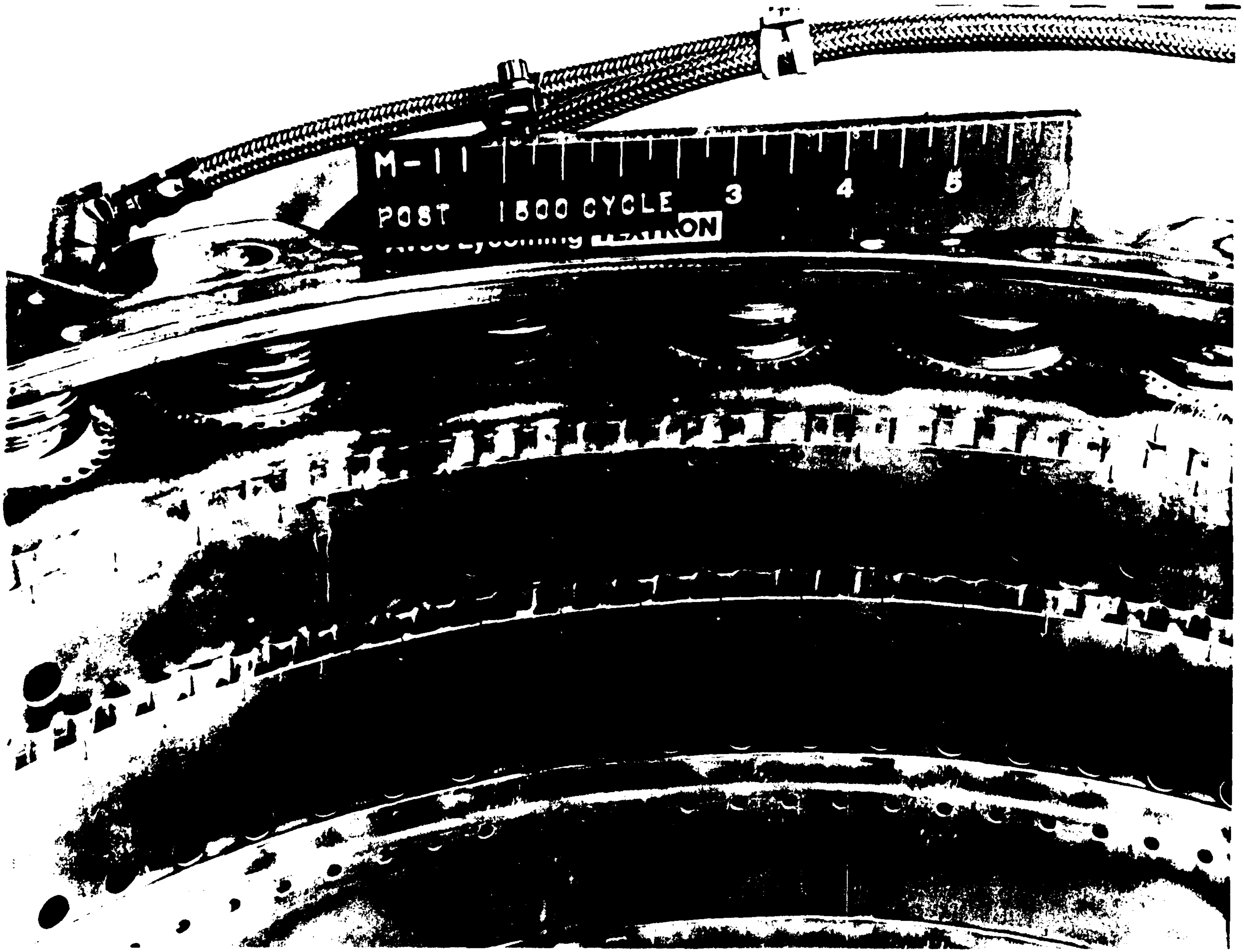


Figure 52 Combustor Liner, Junction Box Hot Spots and Panel Cracking, Post 1500

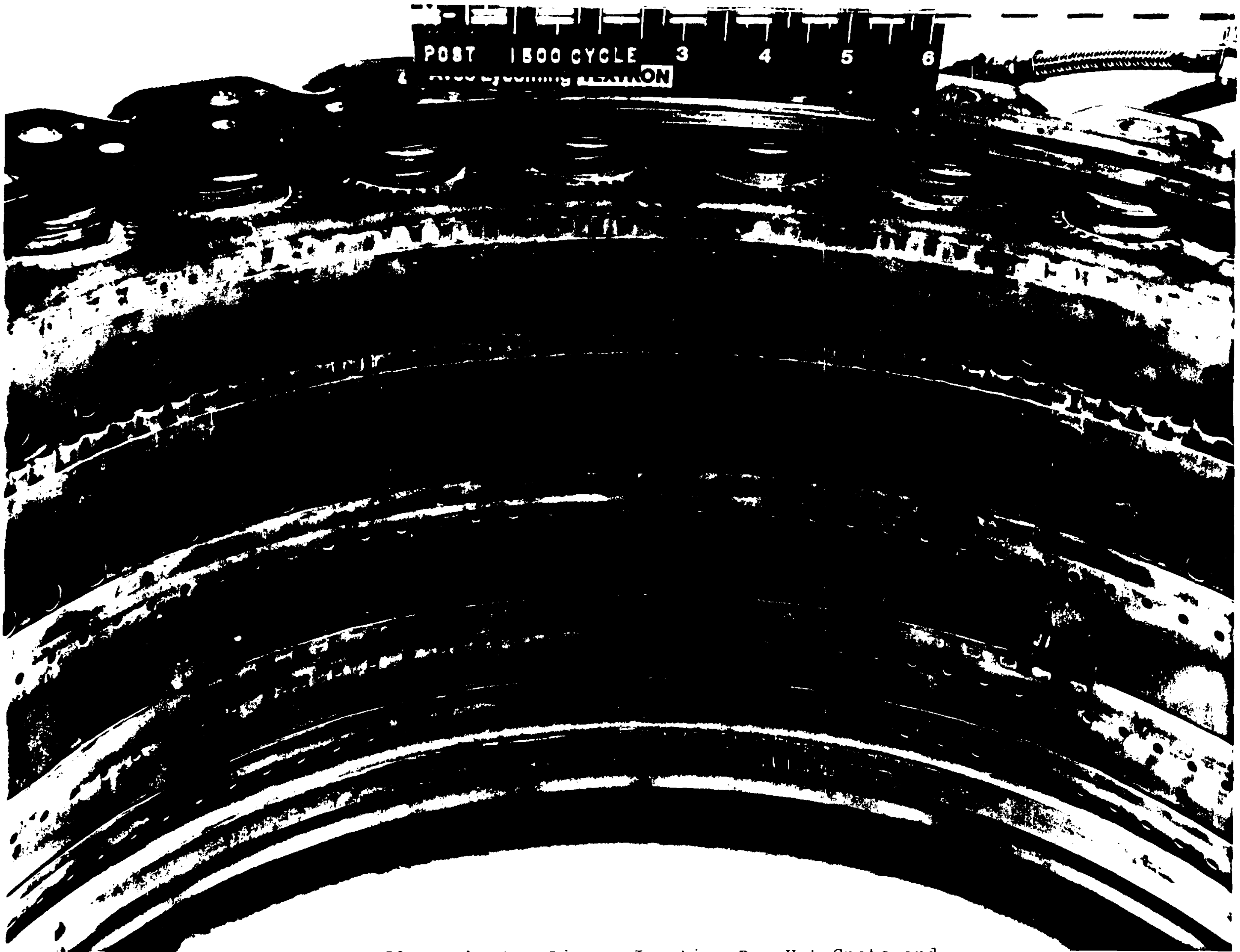
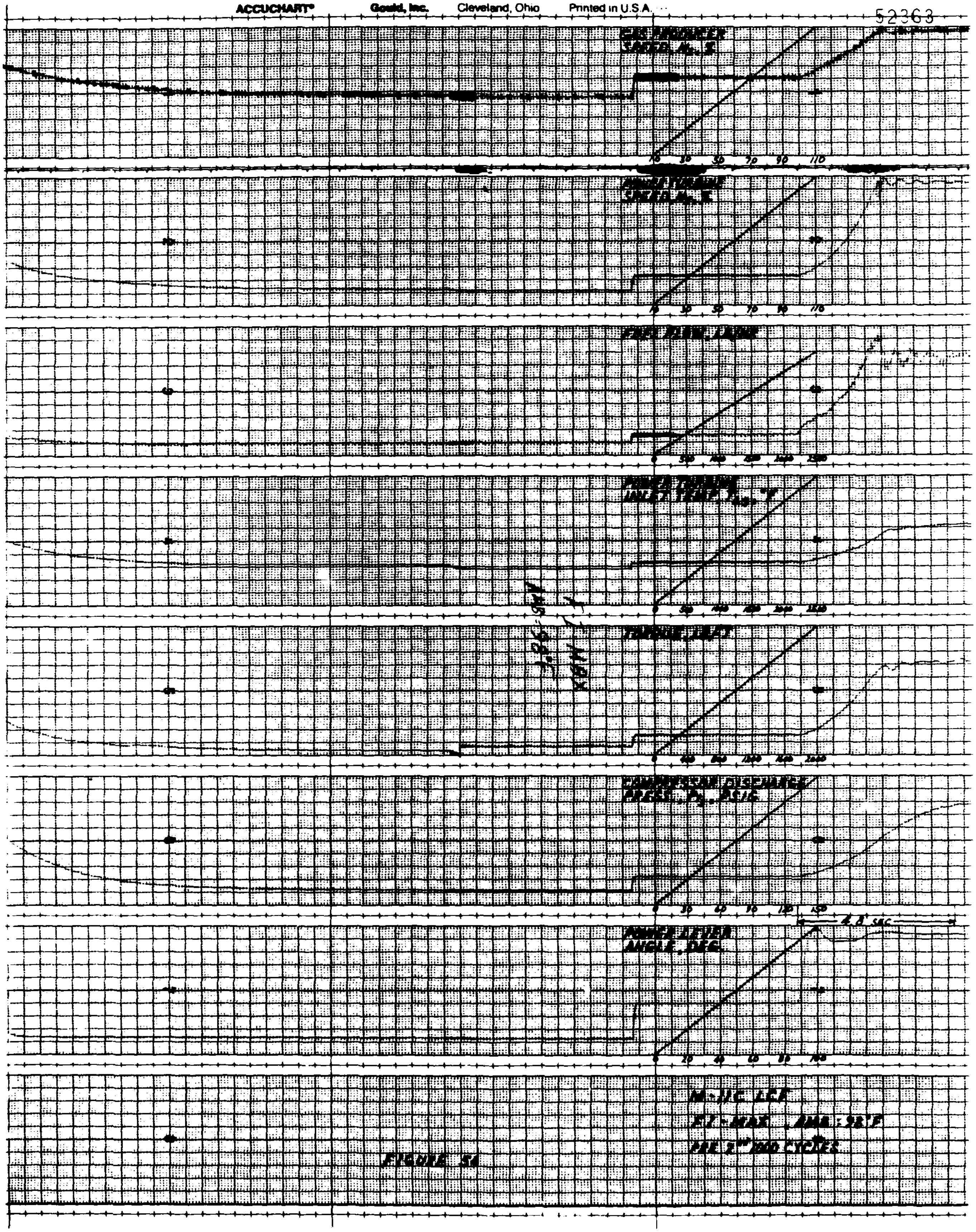
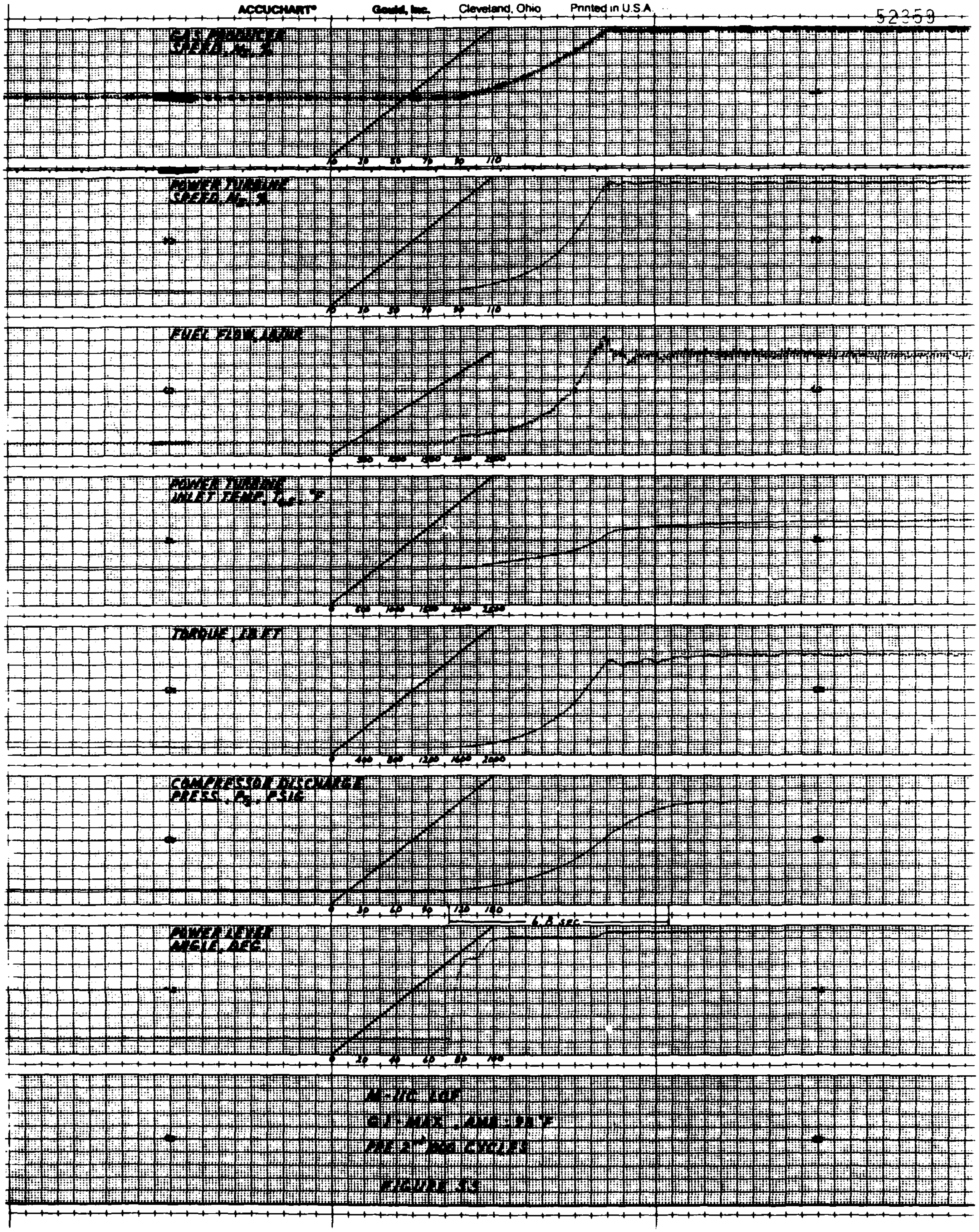


Figure 53 Combustor Liner, Junction Box Hot Spots and
Panel Cracking, Post 1500


ACCUCHART®
Gould, Inc.
Cleveland, Ohio
Printed in U.S.A.
52363
10 30 50 70 90 110
10 30 50 70 90 110
0 20 40 60 80 100


ACCUCHART®
Gould, Inc.
Cleveland, Ohio
Printed in U.S.A.
52359
POWER TURBINE SPEED
POWER TURBINE INLET TEMP.
TORQUE
COMPRESSOR DISCHARGE PRESS., PSIG
POWER LEVER ANGLE, DEG.
6.8 sec

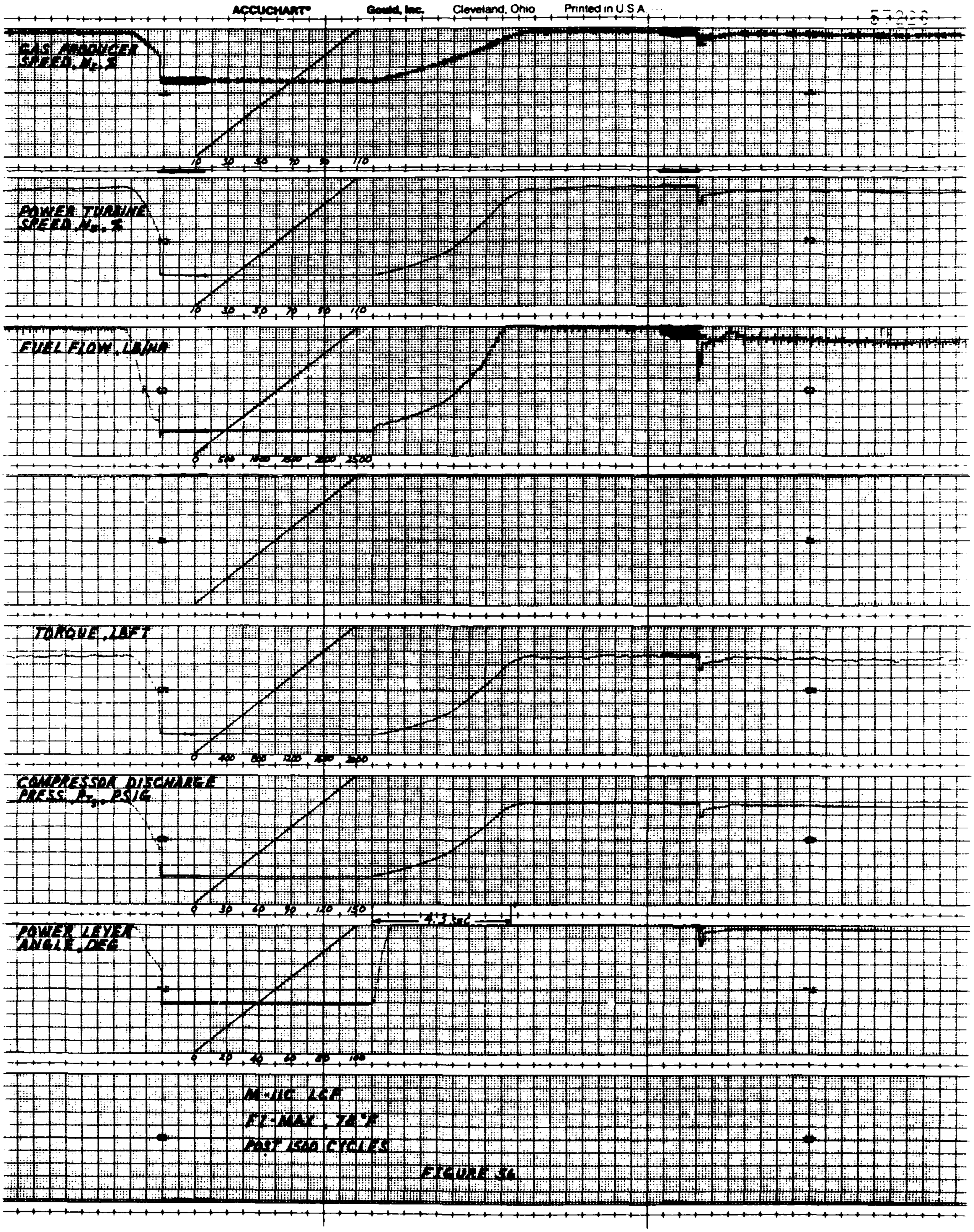

ACCUCHART® Gould, Inc. Cleveland, Ohio Printed in U S A
GAS PRODUCER SPEED, N_g, %
10 30 50 70 90 110
POWER TURBINE SPEED, N_{pt}, %
10 30 50 70 90 110
FUEL FLOW, LB/HR
0 500 1000 1500 2000 2500
TORQUE, LBFT
0 400 800 1200 1600 2000
COMPRESSOR DISCHARGE PRESS. P_{t3}, PSIG
0 30 60 90 120 150
4.3 SEC
POWER LEVER ANGLE, DEG
0 20 40 60 80 100
M-11C LCF
FI-MAX, 78°F
POST 1500 CYCLES

FIGURE 56

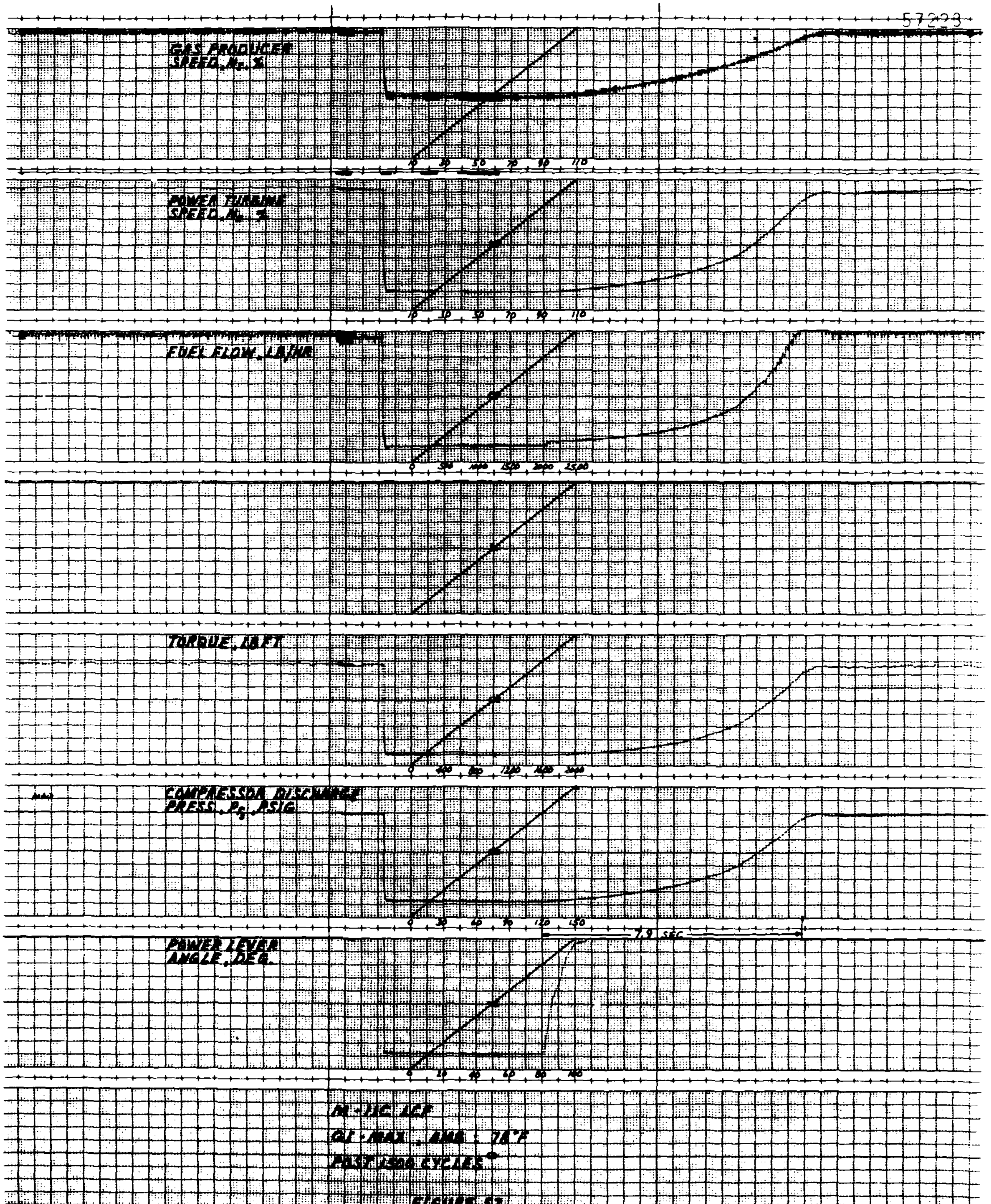

57223
GAS PRODUCER SPEED, N_1, %
10 30 50 70 90 110
POWER TURBINE SPEED, N_2, %
10 30 50 70 90 110
FUEL FLOW, LB/HR
0 500 1000 1500 2000 2500
TORQUE, LB FT
0 400 800 1200 1600 2000
COMPRESSOR DISCHARGE PRESS., P_3, PSIG
0 30 60 90 120 150
7.9 SEC
POWER LEVER ANGLE, DEG.
0 20 40 60 80 100
78°F
POST 1500 CYCLES

FIGURE 57

APPENDICES

APPENDIX I

Avco Lycoming TEXTRON

AVCO LYCOMING TEST SPECIFICATION
XTS 512.2.4

LOW CYCLE THERMAL FATIGUE TEST
ENGINE MODEL T55-L-713

Prepared by
R. Hathaway
Engine Test Manager (Dev.)

Approved by
R. Hathaway
Acting Manager,
Test Engineering

MAY 1986

1. SCOPE

This specification describes the requirements for the conduct of a low cycle thermal fatigue (LCF) test of the T55-L-713 engine. These requirements are in compliance with the applicable portions of Specification AV-E-8593B, as amended by Avco Lycoming Prime Item Development Specification LES 712-86-01.

2. APPLICABLE DOCUMENTS

Military Specification AV-E-8593B
Avco Lycoming Prime Item Development Specification LES 712-86-01, dated TBD. Numbers in parenthesis at the end of paragraphs in this specification denote the applicable paragraph of the PIDS.

3. PRETEST REQUIREMENTS

3.1 Inspection: Engine parts, components, accessories, test apparatus and instrumentation shall be inspected, functionally tested and calibrated, as applicable, subject to witnessing by a government representative. Said representative shall be given all reasonable facilities to determine conformance with this specification.

3.2 Test Engine: Identity of the engine to be used for this test by serial number and parts list and a list of any discrepancies between the parts list and the actual test hardware (including the impact of those discrepancies on the test) shall be submitted to the Government for approval prior to the start of the test. At least the maximum allowable imbalances specified for the engine rotating components and assemblies shall be incorporated prior to engine buildup. (4.2.1, 4.5.9).

3.2.1 Engine Weight: The dry weight of the completely assembled engine shall be determined and recorded prior to delivery to test.

3.2.2 Photographs: Photographs of the completely assembled engine shall be taken prior to test. The photographs will be of sufficient number and clarity to describe the external appearance of the engine.

3.2.3 Engine Fuel System Calibrations: Prior to the initiation of the engine calibration, the components of the power control system and all fuel nozzles shall undergo bench calibrations to determine conformance with the design tolerance range as defined in the applicable control specification. (4.5.1.2)

3.2.4 Temperature Sensing System Calibration: The measured gas temperature sensing system(s) shall be checked to establish its proper functioning over the range of conditions required in the PIDS. The performance shall meet the design tolerance range required by the engine manufacturer. (4.5.1)

4. ENGINE TEST

4.1 Data

4.1.1 Accuracy of Data. For all engine and component calibrations and tests, reported data shall have a steady-state accuracy within the tolerances shown below. Automatic recording equipment and associated test apparatus required to evaluate engine variables versus time shall have a static accuracy within two percent of the values obtained at the intermediate rating of the engine. The accuracy of transient data and the corresponding instrument calibration methods shall be subject to the approval of the authorized Government representative and shall be described in the test reports. All instruments and equipment shall be calibrated as necessary to insure that the required degree of accuracy is maintained. (4.2.21)

Item of Data	
Rotor speed(s)	± 0.2 percent of the value at the Intermediate rating
Power	± 1.0 percent of the value at maximum
Fuel Flow	± 1.5 percent of the value being measured.
Engine Weight	± 2.0 lbs. or ± 0.1 percent of the weight being determined, whichever is greater.
Vibration	± 10.0 percent of specified engine limit, at the specified frequency.
All other data	± 2.0 percent of the value being measured.

4.1.2 Steady-State Data: During the calibrations and performance checks, the following data shall be recorded where applicable. (4.2.2.10)

Time of day
Control lever position, degrees
*Exhaust nozzle area, sq. in. (cold, before and after test)
Gas producer speed, % of 18,720 rpm
Power turbine speed, % of 15,333 rpm
Shaft horsepower, hp
Torquemeter reading, lb-ft
Fuel consumption, lb/hr
Data for determining airflow
Engine inlet total pressure, in. Hg abs
Engine inlet temperature, °F
Compressor discharge total pressure, psi
Compressor discharge total temperature, °F
*Compressor air bleed total pressure, psia
*Compressor air bleed temperature, °F
Exhaust total pressure, (if different from the barometer readings)
Oil pressure at point shown on installation drawing (rear bearing feed), psig

Oil temperature at point shown on installation drawing (pressure pump outlet), °F
Fuel pressure at fuel-system inlet, psig
Fuel pressure at point shown on installation drawing psig
Measured gas temperature, °F
*Fuel temperature, °F
Engine case vibration at points shown on installation drawing, mil
*Ignition source voltage (v) and current (amp), while starting
*Oil leakage at accessory pads

*Items so marked need be recorded during initial and final calibrations only.

4.1.3 Transient Data

4.1.3.1 Power Transient Data: During the calibrations, the following shall be recorded against time, using a suitable oscillograph, for power transients between ground idle and maximum and between flight idle and maximum. (4.2.2.11)

Power lever position, degrees
Gas producer speed, n_I, %
Power turbine speed, n_{II}, %
Compressor discharge total pressure, P_{t3}, psig
Fuel flow, W_f, pph
Measured gas temperature, $T_{T4.5}$ °F
Output shaft torque, lb-ft

4.1.3.2 Starting Data: The following parameters shall be measured during engine starts at the calibration and recalibration. (4.2.2.12)

Start number
Time to ground idle, seconds
Gas producer speed at idle, %
Maximum measured gas temperature during start, °F
Oil pressure (rear bearing feed) at idle, psig
Engine inlet total temperature, °F
Time to ignition, seconds
Time to starter cutout, seconds
Gas generator speed at ignition, rpm
Gas generator speed at starter cutout, rpm
Total time during which the measured gas temperature exceeds 1439°F.
Control lever positions (in degrees)
Oil temperature at measuring point shown on the installation drawing (oil bulb) °F
Time to stabilize to operating oil pressure, seconds
Fuel pressure at measuring point shown on the installation drawing, (boost pump inlet), psig

4.1.4 Cyclic Data: The following data shall be recorded during each cycle of the low cycle thermal fatigue test:

Cycle number
Time to ground idle, seconds
Maximum measured gas temperature during start, °F
Gas producer speed at idle, %
For each acceleration from ground idle:
  Acceleration time, seconds
  Maximum measured gas temperature, °F
  Final gas producer speed, %

In addition, the following data shall be recorded, while operating at maximum and maximum continuous powers during every fourth cycle:

Gas producer speed, %
Power turbine speed, %
Fuel flow, pph
Torque, lb-ft
Measured gas temperature, °F
Engine inlet total temperature, °F

4.1.5 Barometer Readings: The barometer shall be read and recorded at intervals not exceeding three hours. (4.2.2.8)

4.1.5.1 Barometer Correction for Temperature: The barometer shall be corrected for temperature.

4.1.6 Miscellaneous Data: The date, operating schedule, engine model designation, and serial number shall be recorded on each log sheet. (4.2.2.3)

4.1.7 Test Notes: Notes shall be placed on the log sheets of all incidents of the run, such as leaks, vibration, any other irregular functioning of the engine or the equipment, and corrective measures taken. (4.2.2.4)

4.1.8 Fuel and Oil Data: All oil additions made during the test shall be recorded. Samples of the oil shall be taken from the engine for analysis after completion of each 500 cycles. The oil samples removed from the engine, and a sample of unused oil, shall be analyzed for specific gravity, acid number, and kinematic viscosity at 38°C and 99°C. The lower heating value shall be determined for fuel samples taken at the calibration, approximate mid-point of the test, and the recalibration. Specific gravity of the fuel shall be recorded daily. (4.2.2.6)

4.1.9 Correction: Readings of shaft horsepower, rotor speeds, airflow rate, fuel flow rate, specific fuel consumption, gas pressures, and gas temperatures will be referred to standard sea level atmospheric conditions as defined in U.S. Standard Atmosphere, 1976 (NOAA - S/T 76-1562). The correct barometric pressure will be obtained from a barometer external to the test cell and will be corrected for the cell depression obtained by using a pressure pickup at the inlet to the engine. Ambient temperature will be measured by chromel-alumel thermocouples fixed at the engine inlet. (4.2.2.9)

4.2 <u>Test Apparatus</u>

4.2.1 <u>Test Equipment:</u> The following equipment will be used to facilitate the conduct of the test:

4.2.1.1 <u>Power Absorption:</u> A waterbrake will be used to absorb the engine output shaft power. The brake is supported from the engine by an adapter having four beams strain gaged for torque sensing.

4.2.1.2 <u>Starting System:</u> A suitable hydraulic starter with hydraulic pressure supply of sufficient capacity will provide engine starting power.

4.2.1.3 <u>Compressor Airbleed ("customer bleed"):</u> External piping, valving and fixed orifices will be connected to the "customer bleed" port on the compressor housing to provide for 3 percent air bleed, as necessary, to demonstrate maximum permissible air bleed capabilities of the engine.

4.2.2 <u>Data Acquisition Equipment:</u> The following apparatus shall be used to measure and record the required data. Where such equipment is available, an automatic data acquisition system may supplement or supplant the indicating devices noted below:

4.2.2.1 <u>Output Shaft Torque:</u> The support beams of the waterbrake mounting adapter are equipped with calibrated strain gages which sense the output torque. Conversion of strain gage signal to torque indication will be accomplished by suitable signal converter.

4.2.2.2 <u>Rotor Speeds:</u> Rotor speeds will be measured by variable time base digital counters driven by a magnetic speed pickup.

4.2.2.3 <u>Airflow:</u> An inlet nozzle, with ASME-recommended geometry, will utilize throat static pressures and entry total pressures to measure airflow.

4.2.2.4 <u>Pressures:</u> Calibrated Bourdon tube gauges and/or transducers will measure pressures.

4.2.2.5 <u>Temperatures:</u> Temperatures will be measured by C.A. thermocouples. Indication will be by means of digital indicators in conjunction with appropriate signal conditioning equipment.

4.2.2.6 <u>Fuel Flow:</u> A calibrated turbine element with associated signal converter, amplifier and "readout" will be used for fuel flow measurement.

4.2.2.7 Vibration Measuring Equipment: The vibration measuring equipment will consist of CEC Model 4-118 or Vibrametric Model 14C vibration pickups, in conjunction with suitable vibration meter. The meter will have incorporated in its system appropriate filters. Displacement values, peak-to-peak amplitude in mils, and velocity, in/sec, will be recorded by a minimum of two vibration pickups mounted on the engine.

4.2.2.8 Transient Recording: An oscillograph recorder will be used during the engine calibration and recalibration phases to establish transient characteristics of the engine. The following variables versus time will be measured during these calibrations: (1) power lever position; (2) gas producer speed, N_I; (3) power turbine speed, N_{II}; (4) compressor outlet pressure, P_{t3}; (5) fuel flow, W_f; (6) measured gas temperature, (7) output shaft torque.

4.3 Operating Conditions

4.3.1 Test Conditions: Testing shall be conducted under sea level static conditions. Engine inlet temperature may be controlled, if necessary, to maintain the required measured gas temperatures.

4.3.2 Oil Inlet Temperature: The engine has an integral oil system, and oil bulb temperature is a function of inlet air and fuel temperature.

4.3.3 Oil Pressure: The oil pressure shall be adjusted to 50-55 psig at 17,784 (95.0%) gas generator speed and 190°F oil bulb temperature unless limited by the adjustment range of the oil pump.

4.3.4 Accessory Drives: The following accessories and engine components will be installed and run during the LCF test:

I. Accessory Gearbox

1. Power control including fuel pump
2. Lubrication and scavenge pump
3. Gas producer tachometer-generator MS 28054 or magnetic pulse generator mounted on rear of lubrication pump
4. Power turbine speed indication signal generator (Optional - signal may be taken from waterbrake)
5. Fuel boost pump

II Starter Gearbox

1. Starter with torque characteristics not exceeding the minimum applied torque specified in Figure 19 of the PIDS.

4.3.5 Oil Servicing: The oil system shall be drained and filled with new oil at the start of the test. Except for samples, oil shall not be drained from the engine prior to completion of the test unless authorized by the Government.

4.3.7 Filter Servicing: The impending bypass pop-up indicators on oil and fuel filters shall be observed at intervals not exceeding 10 cycles (2 1/2 hours). A filter shall be replaced after first observation of actuation of its impending bypass indicator. When a filter is removed because of impending bypass indication, it shall be examined to determine composition of the entrapped material.

4.4 Method of Test

4.4.1 Engine Calibration: The procedure during the engine calibration shall be such as to establish the performance characteristics of the complete engine prior to the test. Except where otherwise specified, calibrations shall be made with no accessory power extraction, and with no bleed airflow other than that required for continuous engine operation. The following data shall be obtained:

4.4.1.1 Steady-State Calibration: A steady-state calibration shall be conducted to establish the performance of the engine. Performance during the calibration prior to initiation of low cycle fatigue testing shall demonstrate compliance with the sea level performance ratings in Table II of the PIDS, Attachment I of this specification. Data as required in 4.1.2 of this specification shall be recorded. The calibration shall include, as a minimum, the following approximate power levels: maximum, intermediate, maximum continuous, 75% maximum continuous, 40% maximum continuous, flight idle, ground idle.

4.4.1.2 Transient Calibration - Data required in paragraph 4.1.3.1 of this specification shall be recorded to demonstrate the transient performance of the engine. During the transients there shall be no combustion instability or compressor instability. Control lever spindle motion shall be completed in 0.5 seconds or less. The time required to complete 95% of the power change shall not exceed the following at sea level standard conditions:

a. From ground idle to maximum power available, 10.0 seconds
b. From flight idle to maximum power available, 4.0 seconds
c. From maximum power to ground idle, 8.0 seconds
d. From maximum power to flight idle, 6.0 seconds

The change in compressor discharge total pressure (P_{t3}) will be utilized as the indication of the change in shaft horsepower for the purpose of determining transient times. For the purposes of this calibration, flight idle may be established by determining the gas producer speed, N_I, required to produce 16,000 rpm (104.3%) power turbine speed, N_{II}, at no load. If the characteristics of the waterbrake and its control system do not permit attaining zero load, flight idle gas producer speed will be determined from Figure 11 of the PIDS. Accelerations will be demonstrated from the gas producer speed so determined using the power lever.

4.4.1.3 Calibrations with Bleed: The procedures described in 4.4.1.1 and 4.4.1.2 shall be repeated with maximum permissible compressor air bleed (customer bleed).

4.4.1.4 Starting Data: The data specified in 4.1.3.2 of this specification shall be recorded during starts at the time of calibrations.

4.4.1.5 Compressor Bleed Air Analysis: The compressor bleed air shall be sampled from the customer bleed air outlet, with the engine operating at maximum continuous power, at the time of the calibration. A sample of air entering the compressor shall be taken at the same time the bleed air sample is obtained. The samples shall be properly identified and processed through laboratory analysis to determine whether contaminant levels are within the limits specified in 3.18 of the PIDS. The results of the analysis and the methods and test apparatus used shall be detailed in the test report. (4.3.3)

4.4.1.6 Performance Check: After every 100 LCF cycles, approximately, cyclic operation will be interrupted for a brief performance check. This check shall consist of recording of the data of 4.1.2 for at least five power levels, including maximum, intermediate, maximum continuous, 75% MC, and 40% MC.

4.4.1.7 Recalibrations: After completion of each 500 cycles, a recalibration check run shall be made, following the procedures specified in 4.4.1.1 through 4.4.1.5, above, except that calibration with bleed per 4.4.1.3 and customer bleed air analysis per 4.4.1.5 shall be required only after 2000 cycles. During these runs, the power, corrected to sea level standard conditions, shall not be less than 95% of the initial calibration values, and the specific fuel consumption, corrected to sea level standard conditions, shall not exceed 105% of the initial calibration values. The engine shall meet all other specified performance requirements which can be checked by the calibration procedure.

4.4.1.8 Measured Gas Temperature Change. If, during any performance check or recalibration, the corrected measured gas temperature, at any power, changes by more then plus or minus 25°F, the cause and effect of the change shall be evaluated before the test is continued.

4.4.2 Low Cycle Thermal Fatigue Test: The test engine shall be subjected to a total of 2000 cycles of low cycle thermal fatigue testing. This total shall be accumulated in four segments of 500 cycles, each of which shall be followed by evaluation of engine parts condition by performance calibration and inspection as required by 4.5.1.1.

4.4.2.1 Procedure: Following the calibration, the following test cycle shall be used. Measured gas temperature at maximum and maximum continuous powers shall be not less than the measured gas temperature limits for those powers as specified in 3.4.4.2.2.1 of the PIDS. Output shaft speed at maximum power shall be not less than the maximum output shaft speed. The load on the power absorption device shall be adjusted to produce the desired condition at maximum power. Output shaft speed at maximum continuous and ground idle shall be as determined by this preset load.

4.4.2.1.1 Test Cycle:

Approximate Total Time (minutes)	Approximate Schedule Time (minutes)	Event
0.5	0.5	Start engine
2.5	2.0	Run at ground idle
2.6	0.1	Accelerate to maximum power
5.1	2.5	Run at maximum power
5.2	0.1	Decelerate to ground idle
8.2	3.0	Run at ground idle
8.3	0.1	Accelerate to maximum continuous power
10.8	2.5	Run at maximum continuous power
10.9	0.1	Decelerate to ground idle
12.9	2.0	Run at ground idle
15.0	2.1	Shutdown and cool down

4.5 Inspection Requirements

4.5.1 Intermediate Inspections

4.5.1.1 Engine Inspection: After completion of 1000 LCF cycles, the engine shall be disassembled sufficiently to permit inspection of the hot section componnents, i.e., turbines, turbine nozzles, and combustor components, to determine their condition prior to continuation of LCF testing. Discrepancies (cracks, wear, warpage, etc.) will be documented by photographs and/or verbal description, and the results of this inspection will be included in the test report. Additional inspections, consisting of viewing by fiberoptic borescope and/or partial disassembly of the engine, may be performed after 500 and 1500 cycles by mutual agreement between Lycoming and the Government.

4.5.1.2 Component Recalibration: No component recalibration shall be required at the intermediate inspections. However, such calibrations may be performed if data or parts condition indicates the desirability of so doing. If such a recalibration is performed, the results shall be included in the test report.

4.5.1.3 Post Inspection Check: If the engine is disassembled for inspection in accordance with 4.5.1.1, a performance check in accordance with 4.4.1.6 shall be performed after reassembly, prior to resuming the test.

4.5.2 2000-Cycle Inspection

4.5.2.1 Component Recalibrations

4.5.2.1.1 Engine Control System Recalibration: After completion of 2000 LCF cycles, the components of the engine control system shall undergo a bench recalibration to determine conformance with the design tolerance range required by the engine manufacturer. A calibration with control adjustments left at their end-of-test positions shall be followed by a calibration with external engine control adjustments established at their original bench calibration positions.

4.5.2.1.2 Temperature Sensing System Recalibration: After completion of 2000 LCF cycles, the measured gas temperature system shall be rechecked to establish its proper functioning. The performance shall meet the design tolerance range required by the engine manufacturer.

4.5.2.2 Teardown Inspection. After completion of 2000 LCF cycles, the engine shall be completely disassembled for examination of all parts, and measurements, as necessary, to disclose excessively worn, distorted, or weakened parts. These measurements shall be compared with the contractor's drawing dimensions and tolerances or with similar measurements made prior to the test, when available. Posttest balancing of compressor and turbine assemblies shall be accomplished after engine teardown, prior to cleaning the assemblies and after cleaning the assemblies. The results of the pretest and posttest balancing shall be compared in the test report.

5. REPORT

Following completion of 2000 low cycle thermal fatigue cycles, a report shall be submitted.

LOW CYCLE THERMAL FATIGUE TEST
T55-L-713
CYCLE SCHEDULE

ELAPSED TIME MIN: SEC	EVENT	REQ'D CONDITIONS NII	T4.5°F
0:00	Starter and ignitors on		
0:03	Move P/L to Ground Idle Run at Ground Idle	Preset	
2:30	Move P/L to Max. Run at Max. Power	104.4	1644°F
5:06	Move P/L to Ground Idle Run at Ground Idle	Preset	
8:12	Move P/L to Max Cont. Run at Max. Cont.	Preset	1466°F
10:48	Move P/L to Ground Idle Run at Ground Idle		
12:54	Shutdown		
15:00	Begin repeat cycle		

NOTES: Power lever motion should be accomplished in 0.5 seconds or less.

Adjust waterbrake load to give required NII at maximum power condition. Leave this load set for remainder of cycle.

TABLE II

T55-L-713
Performance Ratings at Sea Level, Static, Standard Conditions

RATING	MINIMUM POWER (HP)	MAXIMUM GAS GEN SPEED	RATED SHAFT SPEED	MAXIMUM FUEL FLOW	RATED OUTPUT TORQUE	MAXIMUM MEASURED GAS TEMP
EMERGENCY	4985	20,583	16,000	2550 pph	1636	1665 °F
MAXIMUM	4777	20,250	16,000	2428	1568	1606 °F
IRP	4434	19,734	16,000	2240	1456	1520 °F
MAX CONT	3971	19,228	16,000	2027	1304	1431 °F
PP 1	3490	18,716	16,000	1823	1146	
PP 2	2927	18,118	15,447	1595	995	
PP 3	2340	17,502	14,275	1362	861	

APPENDIX II

ENGINE NO.: M11 TAM NO.: 329-011

DATE: 21 June/87

PREPARED BY: *Mark Wolfram* APPROVED BY: *M. Zoccoli*

M. Wolfram M. Zoccoli

DISTRIBUTION

A. Boutin
T. Craft
R. DiGiovanni
W. Dornfeld
R. Hathaway
R. Haugland
J. Hewitt
J. Kasmarik
J. Kolar
J. Kozub
J. Micheli
R. Stevens
D. Tate
H. Vogel
M. Wolfram
M. Zoccoli
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M11 TEARDOWN

1.0 INFORMATION

1.1) Engine M11 (T55-L-713) is to be rebuilt for the second half of the 2000 cycle LCF test required as part of the T55-L-713 qualification. The engine's hot section was disassembled for inspection at the 1000 cycle point. The inspection revealed second nozzle distress; approval was obtained to rework the nozzle to 2-121-100-R72 confirguration which is the 2-121-100-61 nozzle with the superflex baffle. In addition, a new set of 960 series MGT probes with modified junction boxes will be installed for the purpose of reducing interference with combustor liner. Remaining engine assembly to be the same as the last build.

2.0 INSTRUCTIONS

2.1 Remove combustor liner, third nozzle and support.

2.2 Remove MGT probes from third nozzle support.

2.3 Install new MGT probes with reduced height junction boxes (probes located on rack).

2.4 Reinstall third nozzle assembly and complete remaining combustor PT assembly.

2.5 Install first GP nozzle with cylinder (temp. bolted). Adjust nozzle/cylinder to obtain best runouts at cylinder, also check 2nd nozzle pilot first nozzle. Notify engineering of results before safety wiring and installation of first GP wheel.

2.6 Complete GP assembly using reworked se[illegible] nozzle 2-121-100-R72 SN 37.

2.7 Measure and record all fits and [illegible] assembly.

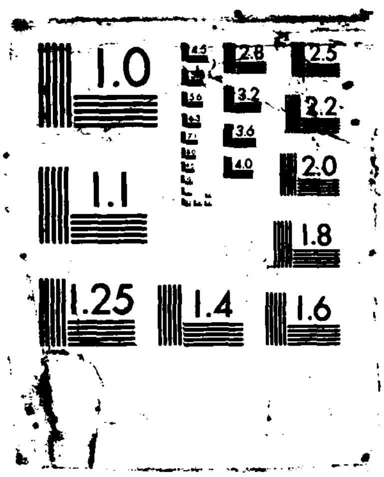
2.8 Install combustor PT assem[illegible] for test.

3.0 INSPECTION

3.1 Provide coverage [illegible]

AD-A192 765   I55-L-714 ENGINE DEVELOPMENT AND QUALIFICATION ENGINE   2/2
MIL LOW CYCLE FATIG..(U) AVCO LYCOMING ENGINE GROUP
STRATFORD CONN STRATFORD DIV J KOZUB DEC 87 LYC-87-14
UNCLASSIFIED   DAAJ09-87-C-A043   F/G 21/5   NL

END
DATE
FILMED
8


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

ENGINE NO.: M11

TAM NO.: 329-011 Supp. 1

DATE: 25 June 1987

PREPARED BY: M. Wolfram
M. Wolfram

APPROVED BY: A. Boutin
A. Boutin

DISTRIBUTION

A. Boutin
T. Craft
R. DiGiovanni
W. Dornfeld
R. Hathaway
R. Haugland
J. Hewitt
J. Kasmarik
J. Kolar
J. Kozub
J. Micheli
R. Stevens
D. Tate
H. Vogel
M. Wolfram
Eng'r. Library

M11 TEARDOWN

1.0 INFORMATION

1.1 This Supplemental TAM continues the assembly of engine M11 for the second 1,000 cycle LCF test. Shortly after the start of this assembly, loose third stage turbine blades were discovered. The P.T. was disassembled for shroud gap measurement and rivet replacement.

2.0 INSTRUCTIONS

2.1 Balance third turbine assembly.

2.2 Install oil pump (removed for check valve cleaning).

2.3 Remove and replace oil filter (new filter on rack).

2.4 Assemble combustor P.T. assembly.

2.5 Complete engine assembly and prepare for test.

3.0 INSPECTION

3.1 Provide coverage as required.

APPENDIX III

LYCOMING DIVISION
STRATFORD, CONNECTICUT

MATERIAL EXAMINATION REPORT

E201CC10

LAB. NO. X27940
DATE 7-21-82

NO. 43590 HEAT NO. ______ P. O. ______ R. R. ______ QUAN. ______

NAME TURBINE FUEL JP-4 PART NO. MIL-T-5624

MIL CELL 05 VENDOR Kozub

CH TCE 6000 min SHIPMENT

	GRADE JP4		GRADE JP5	
TEST	REQUIRED	LYCOMING	REQUIRED	LYCOMING
Distillation				
Initial Boiling Point °F	record	146	record	
10% Recovered at, °F	record	180	401 max.	
20% Recovered at, °F	293 max.	196	record	
50% Recovered at, °F	374 max.	312	record	
90% Recovered at, °F	473 max.	440	record	
End Point, °F	518 max.	480	554 max.	
Residue, Volume %	1½ max.	1	1½ max.	
Loss, Volume %	1½ max.	1	1½ max.	
Freezing Point, °F.	-72 max.		-51 max.	
Heat of Combustion, Net				
BTU/lb. or	18400 min.	18,731	18300 min.	
Aniline Gravity Product	5250 min.		4500 min.	
Gravity, °API	45 - 57	53.9	36 - 48	
Water Reaction	1b. max.		------	
Flash Point, °F	------		140 min.	
Total Sulfur, wt. %	0.4 max.		0.4 max.	

NOTE: PRE 2nd 1000 ~

DISPOSITION ______

______ DATE

X

Avco Lycoming TEXTRON

OIL ANALYSIS

MATERIALS AND PROCESS TECHNOLOGY LABORATORIES

LAB NO.	X2P131	LAB. DATE	8-28-87	ENGINE ~~HOURS~~	8007 min
SAMPLE NO.	43743	TAG DATE	8-27-87	CYCLES	500
ENGINEER	Kozub	EXT.		OIL ~~HOURS~~	8007 min
ENGINE MODEL	T55 L713	S/N	M-11C	WORK ORDER	E2010010
ENGINE USER	cell 05	VEHICLE / A/C			

OIL RESULTS:

Oil Spec:

Acid Number: ______

Viscosity: ______ CS @ 100°F

Flash Point: ______ °F

Foam: ______/______ ml foam/collapse time sec ______ °F

Visual: ☐ Accept ☐ ______

SPECTROMETRIC RESULTS: Wear metals in parts per million

Sample	Comments	Fe	Ni	Ag	Cu	A1	Mg	Cr	Zn	Si	
43743	After 500 LCF cycles	2	<1	<1	2	<1	2	<1	9	1	

REMARKS POST 1500 N

FERROGRAM RESULTS:

Sample Volume Passed thru D.R. ______ ml

Sample Volume Passed Along Ferrogram ______ ml

Ferrogram No.: ______

D.R. Reading: L ______ S ______

Severity Index (L + S) ______

TYPE OF PARTICLES	None	Few	Several	Heavy
Normal Rubbing Wear				
Fatigue Chunks (typical gear surfaces fatigue)				
Spheres (fatigue cracks in rolling bearings)				
Laminar Particles (gears or rolling bearings)				
Severe Wear Particles				
Cutting Wear Particles (high unit pressure)				
Dark Metallo-Oxide Particles (typical hard steels)				
Non-Ferrous Metallic				
Non-Metallic, Crystalline				
Non-Metallic, Amorphous				

Estimated Wear Situation: ☐ Very Low ☐ Normal ☐ Caution ☐ Very High

KE

RSA-404

Avco Lycoming TEXTRON

OIL ANALYSIS

MATERIALS AND PROCESS TECHNOLOGY LABORATORIES

AB NO.	X27957	LAB. DATE	7-25-87	ENGINE HOURS	10
LE NO.	43591	TAG DATE	7-21-87	CYCLES	
NGINEER	Kozub	EXT.		OIL HOURS	10
ENGINE MODEL		S/N	M11	WORK ORDER	E2010010
ENGINE USER	Cell DT	VEHICLE / A/C			

OIL RESULTS:

Oil Spec:

Acid Number: ________

Viscosity: ________ CS @ 100°F

Flash Point: ________ °F

Foam: _____/_____ ml foam/collapse time sec _____ °F

Visual: ☐ Accept ☐ ________

SPECTROMETRIC RESULTS: Wear metals in parts per million

Sample	Comments	Fe	Ni	Ag	Cu	A1	Mg	Cr	Zn	Si	
43591	G/B	2	1	<1	1	<1	1	<1	6	1	

REMARKS PRE 2nd 1000 ~

FERROGRAM RESULTS:

Sample Volume Passed thru D.R. ________ ml

Sample Volume Passed Along Ferrogram ________ ml

Ferrogram No.: ________

D.R. Reading: L _____ S _____

Severity Index (L + S) ________

TYPE OF PARTICLES	None	Few	Several	Heavy
Normal Rubbing Wear				
Fatigue Chunks (typical gear surfaces fatigue)				
Spheres (fatigue cracks in rolling bearings)				
Laminar Particles (gears or rolling bearings)				
Severe Wear Particles				
Cutting Wear Particles (high unit pressure)				
Dark Metallo-Oxide Particles (typical hard steels)				
on-Ferrous Metallic				
Non-Metallic, Crystalline				
Non-Metallic, Amorphous				

RSA-486

Estimated Wear Situation: ☐ Very Low ☐ Normal ☐ Caution ☐ Very High

REPORT NO LYC 87-3
(0213-001-87)

LOW CYCLE FATIGUE TEST
SUMMARY OF FIRST 1000 CYCLES

T55-L-713 ENGINE S/N M11

Prepared by: J. Kozub Jr.
J. Kozub
Test Engineer

Approved by: R. Hathaway
R. Hathaway
Engine Test Manager

Concurred by: M. Zoccoli
M. Zoccoli
Manager
T55 Engine Projects

APRIL 30, 1987

ENGINE TEST REPORT

REPORT SERIAL NO.: 0213-001-87 DATE ISSUED: 4/29/87

ENGINE MODEL: T55-L-713 CHARGE NO.: E7852151

ENGINE NO.: M-11 BUILD LETTER: B

OBJECT(S) OF TEST (Run Code)

1000 Cycle LCF Test

SUMMARY

T55-L-713 engine M-11B successfully completed a 1000 cycle LCF test on 24 November 1986. With the exception of the 2nd nozzle (cracked cooling air baffle) and several fractured compressor housing/air diffuser mounting bolts, the engine completed the test in good to excellent condition.

Average actual operating conditions demonstrated were:

	NI*	SHP	$T_{4.5}$	$T_{4.5}$ Required
Maximum	108.5%	4714	1654°F	1650°F
Max. Continuous	104.3%	3975	1506°F	1500°F

*100% = 18,720 RPM

Following the weld repair of the 2nd nozzle, the engine will be reassembled and subjected to a second 1000 cycle LCF test.

Test Engineer: J. Kozub J. Kozub Jr.

TEST CELL	DATE INSTALLED	DATE REMOVED	ENGINE RUN TIME ELAPSED	ENGINE RUN TIME ENDURANCE
D-5	20 Sept 86	24 Nov 86	250.93 Hr	216.67 Hr

STARTS: NO. 1000 ; TYPICAL TIME 22.1 sec. ; TYPICAL MGT/ 1138°F

No. of Idle-Flight Power*-Idle Cycles: 2000

No. of Excursions to Emergency Power*: N/A

No. of Operating Cycles*: 1200 (See Figure 5 for test cycle)

*If defined for engine model; operating cycle probably not same as test cycle.

OIL TYPE	VENDOR (If Applicable)	FUEL
23699	American Oil Supply	JP-4

REASON FOR REMOVAL

TEST COMPLETED X ; FAILED ______ ; OTHER (Specify) ______

CAUSE OF FAILURE (If Applicable):

PHOTO NEGATIVE NOS.

OTHER RELATED REPORTS (EXS, TM, ETC): Memo #D9-e-299-B6; Performance Analysis of T55-L-713 1000 Cycle LCF Engine M-11A.

This report submitted to Army as LYC 87-3.

T55-L-713

M-11B

1000 CYCLE LCF SUMMARY

On 24 November 1986, T55-L-713 engine M-11B completed 1000 low cycle fatigue (LCF) cycles. The test was performed in accordance with Experimental Test Specification XTS 512.2.4. The test defined therein is that specified for the T55-L-712 engine in Prime Item Development Specification (PID'S) 124.53B, with demonstrated gas temperature requirement adjusted to -713 levels. The test cycle is depicted graphically in Figure 5. The test was performed using MIL-T-5624, Grade JP-4 fuel, and MIL-L-23699 oil.

Engine M-11 was originally built and sold to the U.S. Army as a T55-L-712, S/N LE71429. The engine was assigned to the Power Margin Durability Program for use in the LCF test. The conversion to the L-713 configuration was performed in accordance with Test and Assembly Memorandum No. 329-004 and 329-006. These are included as Attachment 1.

Calibrations were conducted before cycling, after 500 cycles, and after 1000 cycles to determine that the engine met the pretest and posttest performance requirements of the PIDS. Pretest sea level standard day performance at the rated powers was:

		Wf,LB/HR		$T_{4.5}$, °F		NI, % *	
POWER RATING	SHP	SPEC MAX	DEMO	SPEC MAX	DEMO	SPEC MAX	DEMO
Emergency	5028	2563	2468	1681	1641	109.9	109.0
Maximum	4818	2438	2330	1621	1585	108.2	107.3
Intermediate	4472	2254	2189	1538	1507	105.6	104.7
Max Continuous	4110	2087	2030	1470	1438	103.4	102.1

*100% = 18,720 RPM

The preceding data indicates that the subject engine met pretest performance guarantees. Posttest performance data showed there was some degradation though the degree of degradation was well within that expected for 1000 LCF cycles. Table 1 and Figures 1-4 show that fuel flow and gas producer inlet temperature (T4.1) for a given horsepower increased an average of only .34% and .58% respectively. Gas producer speed increased an average of .3%. The 43°F decrease in power turbine inlet temperature (T4.5) was a result of an apparent change in the MGT harness (discussed below).

A tabulation of average actual operating conditions demonstrated during testing follows:

	NI	SHP	$T_{4.5}$	$T_{4.5}$ Required
Maximum	108.5%	4714	1654°F	1650°F
Max Continuous	104.3%	3975	1506°F	1500°F

Mechanically, the engine and all accessories functioned satisfactorily with the exception of the measured gas temperature (MGT) harness. During the post 500 cycle hot end inspection a harness thermocouple check indicated that the 12:00 position was electrically open. The thermocouple was replaced and testing continued. While all (5 pairs) thermocouples were indicating for the remainder of the test, the MGT data appears to have shifted. The shift was not supported by any corresponding changes in other performance parameters. An investigation of the harness is underway.

The physical condition of all hardware, except the 2nd nozzle and compressor housing/air diffuser mounting bolts, several of which were loose or fractured, was acceptable and capable of continued satisfactory operation.

The 2nd nozzle suffered a 330° crack in the cooling air baffle. While the structural integrity of the nozzle is not affected, the path for the cooling air is. The nozzle will be weld repaired and used in the engine for the next 1000 cycle test.

A preliminary investigation of the fractured bolts indicates low cycle fatigue to be the primary cause. A mixture of low alloy steel and A826 bolts were used (allowable per print) for the assembly though only the steel bolts fractured. Hardness and chemical composition were acceptable.

It is recommended that engine M-11B be reassembled for a second 1000 cycle test utilizing all of the previous builds hardware. This assumes the weld repair of the 2nd nozzle is satisfactory.

TABLE 1

PRETEST VS. POSTTEST
PERFORMANCE

SHP	Wf, LB/HR PRE	POST	Δ	% Δ
5028	2481	2501	+20	+.81
4818	2355	2360	+ 5	+.21
4472	2190	2192	+ 2	+.09
4110	2025	2030	+ 5	+.25

SHP	$T_{4.1}$, °F PRE	POST	Δ	% Δ
5028	2103	2120	+17	+.81
4818	2038	2049	+11	+.54
4472	1949	1957	+ 8	+.41
4110	1864	1874	+10	+.54

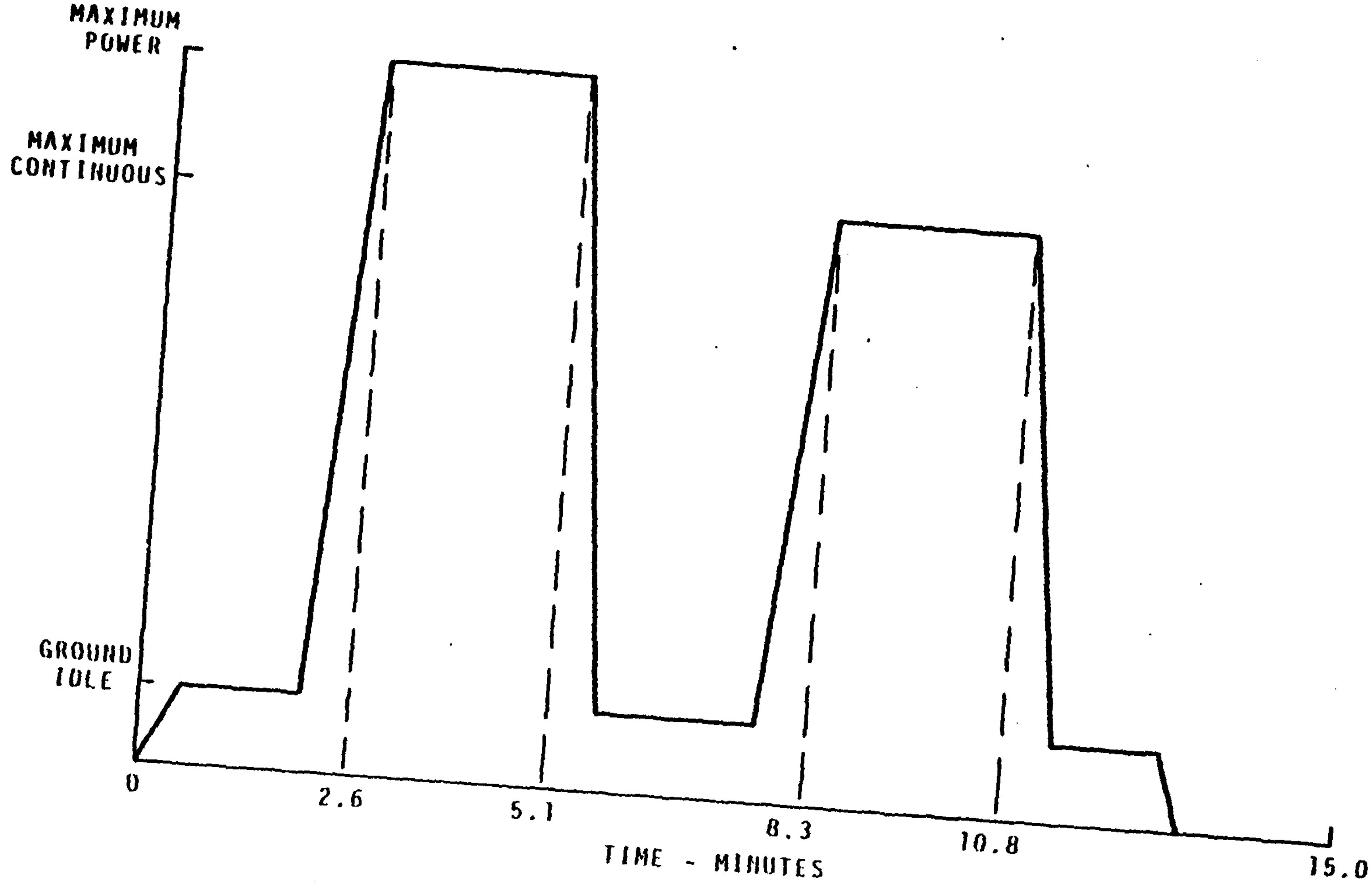
SHP	$T_{4.5}$, °F PRE	POST	Δ	% Δ
5028	1641	1594	-47	-2.95
4818	1586	1541	-45	-2.92
4472	1508	1467	-41	-2.79
4110	1436	1396	-40	-2.87

SHP	NI, % PRE	POST	Δ	% Δ
5028	108.9	109.1	+ .2	+.18
4818	107.3	107.6	+ .3	+.28
4472	104.8	105.1	+ .3	+.29
4110	102.3	102.7	+ .4	+.39

T55-L-713

LOW CYCLE THERMAL FATIGUE TEST

(ONE CYCLE)



AVCO LYCOMING DIVISION
STRATFORD, CONN.

FIG 5

ENGINE NO.: M-11 TAM NO.: 329-004

PROJECT NO.: E7852150 DATE: 10 September 1986

PREPARED BY: Mark Wolfram
M. Wolfram

APPROVED BY: M. Zoccoli
M. Zoccoli

DISTRIBUTION

W. Brown
T. Craft
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M-11 BUILD

1.0 INFORMATION

1.1) Engine M-11 (LE71429) a new production T55-L-712 is to be converted to a T55-L-713 beginning with this TAM and supplements as required. This engine will be part of the T55-L-713 qualification program. The build will follow the 2-001-020-28 bill of materials Due to the limited teardown only part numbers revealed during conversion will be checked with the bill of materials.

2.0 INSTRUCTIONS

2.1) Listed below are the major hardware changes for this conversion:

- PSK20277 SN1188 Air Diffuser
- PSK25888 Curl
- PSK25889 Baffle
- 2-121-430-25 1st Nozzle
- 2-121-090-42 1st Turbine SNM375552
- 2-121-470-20 1st Cylinder
- 2-121-100-61 Nozzle, 2nd
- 2-121-071-30 Spacer
- 2-141-338-06 3rd Support
- 950 Series MGT Probes
- Water Wash ECP 55-251 - See Attachment
- 4 & 5 Brg. Pkg. Improvements
- 0-141-032-01 Sleeve

2.2) Balance GP turbines as an assembly to the upper half of the specification (Qual. test requirement). Clearly mark for reassembly.

2.3) Repeat 2.2 for PT assembly.

2.4) Install two 0-141-032-01 seal runners in #2 brg. pkg.

2.5) Thoroughly clean air diffuser PSK20277 SN1188, flow oil passages. (Recently reworked)

2.6) Install bearing package on diffuser and flow check. Install diffuser.

cont'd

ENGINE NO.: M-11 TAM NO.: 329-004

PROJECT NO.: E7852150 DATE: 10 September 1986

PREPARED BY: Mark Wolfram APPROVED BY: M. Zoccoli

M. Wolfram M. Zoccoli

M-11 BUILD **(PAGE 2)**

2.0 INSTRUCTIONS (cont'd)

2.7) Install water wash system (see attachment).

2.8) Thoroughly clean (remove coke) from PT shaft and compressor shaft ID.

2.9) Additional instructions to follow.

3.0 INSPECTION

3.1) Provide coverage as required.

MW/lea

ENGINE NO.: M-11 **TAM NO.:** 329-006

PROJECT NO.: E7852150 **DATE:** 10/3/86

PREPARED BY: Martin Wolfram
M. Wolfram

APPROVED BY: M. Zoccoli
M. Zoccoli

DISTRIBUTION

W. Brown
T. Craft
D. Collings
R. DiGiovanni
J. Gardini
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1.0 INFORMATION

1.1) Engine M11 has completed green run teardown inspection. The engine will now be built in preparation for a 1000 cycle LCF test.

2.0 INSTRUCTIONS

2.1) Assemble 1st nozzle per print 2-121-430-25 ADV, APD for flow check.

2.2) Remove existing cap and oil filter from assy. gearbox and install high capacity filter P/N 2-300-962-01 and cap P/N 2-300-953-01. See 2-080-020-42 for assembly.

2.3) Remove SGB seal 2-300-138-01 and install seal 2-300-138-02G.

2.4) Check balance GP rotors, correct as necessary to result in a balance of the assembly that will be in the upper half of the specification.

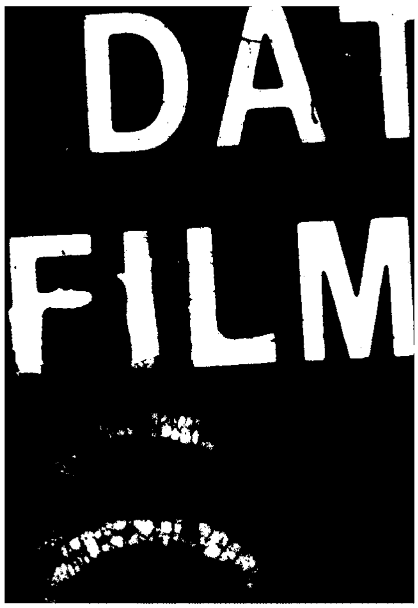
2.5) Assemble G.P. section using hardware from last build with one possible exception of the 2nd nozzle bumper, a P/N 2-121-222-02 bumper will be available. Measure and record fits and clearances as necessary.

2.6) Install PT assembly and prepare engine for test.

3.0 INSPECTION

3.1) Provide coverage as required.

MW/lea


DAT
FILM